RT NO. UMTA-MA-06-0049-78-9

TSC Urban & Regional Research Series

Modeling Demand-Responsive Feeder Systems in the UTPS Framework

Final Report
July 1978

UMTA Office of Planning Methods and Support

U.S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration
and Transportation Systems Center

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0049-78-9		

4. Title and Subtitle	5. Report Date
MODELING DEMAND-RESPONSIVE FEEDER SYSTEMS IN THE UTPS FRAMEWORK	July 1978
	6. Performing Organization Code
7. Author's)	8. Performing Organization Report No.
H.R. Menhard, M. Flusberg, L.S. Englisher	DOT-TSC-UMTA-78-23
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Multisystems, Inc. 1050 Massachusetts Ave. Cambridge MA 02138 (Under subcontract to Cambridge Systematics, Inc. Cambridge MA 02138) *	UM817/R8704
	11. Contract or Grant No.
	DOT-TSC-977
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Urban Mass Transportation Administration Office of Transportation Planning Management and Demonstrations Washington DC 20590	Final Report April 1977-Jan. 1978
	14. Sponsoring Agency Code

15. Supplementary Notes

*Under contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract

Demand-responsive transportation (DRT) systems have been increasingly proposed as feeder services to fixed transit routes in low density areas. The analyst wishing to plan such services as part of a regional transit network has had no tools available for analyzing DRT feeder systems. A methodology for considering such services with the framework of UTPS modeling is provided in this report.

A set of previously developed DRT supply models, representing many-to-many service, many-to-one cycled service, and many-to-one subscription service have been adapted and refined. These services are discussed, and general guidelines for designing feeder services offered. The models themselves are described, and program listings provided. In addition, a series of nomographs based on model results have been developed to enable the analyst to predict the service levels of DRT feeder systems under a range of conditions without actually exercising the models themselves.

A general methodology for analyzing DRT feeder systems within the UTPS framework is discussed. Several examples, utilizing the aforementioned nomographs, are then provided.

17. Key Words	18. Distribution Statement
Demand-Responsive Transportation Integrated Transit/Paratransit Transit Supply Models UTPS	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	168	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

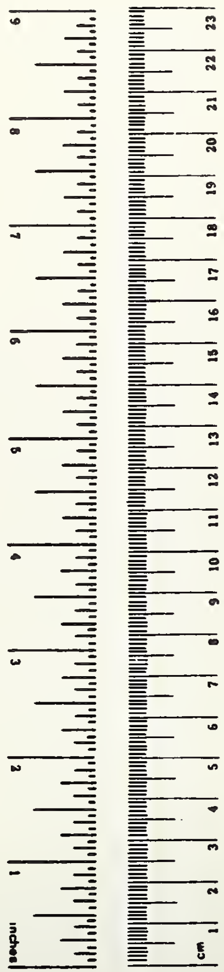
PREFACE

Multisystems, Inc. wishes to thank Howard Simkowitz and Donald Ward of the U.S. Department of Transportation, Transportation Systems Center, and Tom Hillegas, of the Urban Mass Transportation Administration for their efforts in directing the research that led to this report. Multisystems, Inc. would also like to thank Wayne Pecknold, Steven R. Lerman, and Richard Nestle of Cambridge Systematics, Inc. for their input during earlier phases of this research effort. Last, but not least, the authors wish to thank Jorge Carbonell and Jo Ann Kruger for their graphics contribution, and Pamela J. Montgomery for her typing and administrative support.

METRIC CONVERSION FACTORS

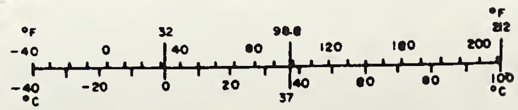
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inchss	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.
INTRODUCTION

As low density development in metropolitan areas has continued and trip patterns have dispersed, it has become increasingly difficult to provide adequate transit service to outlying areas. Line haul routes through suburban areas typically are accessible by walking to only a small percentage of residents. An extensive feeder system may be necessary to provide sufficient coverage in low density areas, but such a network can be very expensive to operate. The concept of park and ride has become more popular and, in many instances has proven extremely successful for trips from the suburbs to the CBD. However, this requires an automobile which is left inactive all day at a park and ride lot; "kiss-and-ride" may be more feasible, but quite inconvenient for many households.

In recent years, considerable attention has been focused on the use of demand-responsive transportation (DRT) systems to provide feeder service in low density areas. In a DRT system, vehicles respond in some manner to the demands of the passengers, frequently providing door-to-door service. By traveling only to areas from which there is demand, and by offering door-to-door service, DRT feeder systems avoid some of the inefficiencies of fixed route systems in low density areas, while simultaneously offering passengers a level of service more comparable to that of the automobile. A variety of types of DRT systems have been designed, as will be discussed in Chapter 2.

The ability of a DRT system to serve diverse travel desires also makes it suitable for serving off-peak trips. Plans for the development of integrated fixed route/DRT systems have included

the concept of DRT feeder/fixed route line haul systems operating during the peak hours, with expanded DRT zones and contracted fixed route networks during the off-peak. (Ward, 1976) This type of concept is illustrated schematically in Figure 1.1.

For the transit planner considering alternative future transit designs, there has been little in the way of analytical tools available to assess the impact of DRT systems. The Urban Transportation Planning System (UTPS), perhaps the most widely used transit planning methodology, is oriented towards fixed transit networks. In defining transit networks for UTPS, wait time for fixed route service is typically extimated as a function of headway, while ride time can be derived from speeds and route lengths. In DRT systems, however, there are neither headways nor routes from which to derive travel time estimates. Planners wishing to consider DRT services in the UTPS framework have typically had to "guess" the DRT system's service characteristics, if they were to consider DRT at all.

This report is intended to provide the UTPS user with a methodology for incorporating DRT feeder systems in transit network analysis. A set of previously developed DRT supply models, representing a number of DRT feeder modes, have been refined for the purposes of this report, which focuses on the way in which the results of these models can be used to analyze DRT feeder systems. A basic knowledge of UTPS programs and conventions is presupposed, and the report does not deal with UTPS procedures in depth. Specifically, Chapter 2 presents a discussion of different types of DRT feeder services. In Chapter 3, the DRT feeder models are briefly outlined. The ways in which the model results can be utilized in the UTPS framework are discussed in Chapter 4. The models are discussed in detail including flowcharts that will enable the user to exercise the models with an electronic calculator, in Appendix A. Nomographs based on model results are presented in Appendix B; these results should

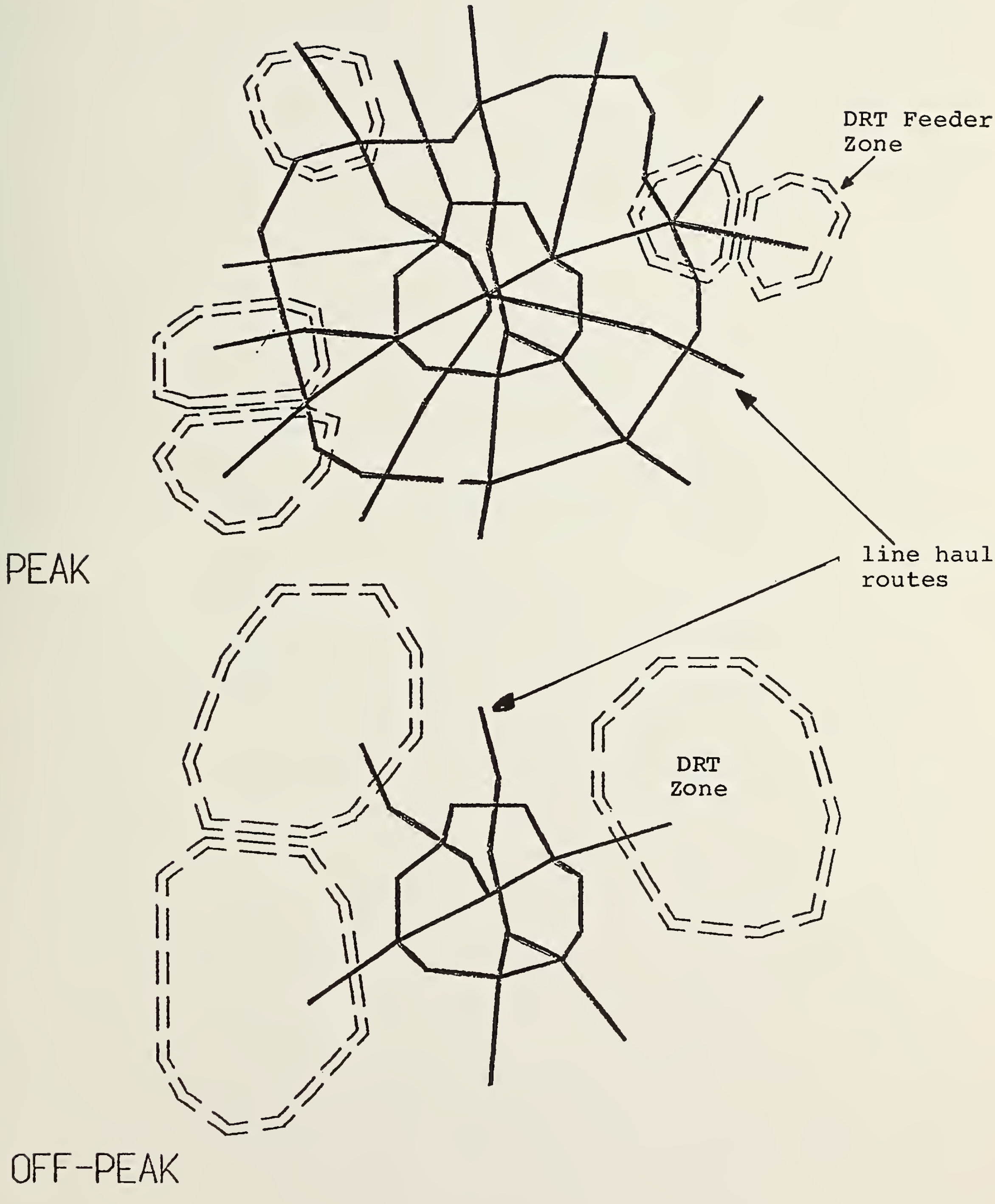

Figure 1.1
Potential Transit Network Scenarios

obviate the need of the UTPS user, in most cases, to actually exercise the DRT models themselves. Examples of the use of these nomographs, and the overall approach to modelling DRT feeder systems within UTPS, are also included in Appendix B. The models have been computerized, and program listings and input descriptions are included in Appendix C. Finally, the definitions of terms, as used in this report, are provided in the Glossary.

2.
Demand-Responsive Feeder Systems

Introduction

As noted in the previous chapter, a variety of types of demand-responsive transportation systems can be used to provide feeder service. In this chapter, the systems that have been modeled for the purposes of this report are described. In addition, certain guidelines that can be used in designing feeder systems are suggested.

2.1 Basic System Descriptions

2.1.1 Many-to-Many Service

A "many-to-many" system is perhaps the best known of all demand-responsive systems. (US DOT, 1974) Commonly referred to as "dial-a-ride" (a term which, unfortunately, is also used to describe other types of DRT systems), many-to-many is, at once, the most flexible of all DRT systems, and the most frequently implemented. In a many-to-many system, point-to-point service is provided anywhere within a service area. Typically, service is provided on an "immediate request" or "dynamic dispatch" basis; i.e., an attempt is made to pick up a passenger as soon as possible after the request for service. In most systems of this sort, some passengers will also make "advance requests" for service, i.e., call in at least a few hours or perhaps several days before the desired trip time, to reserve a vehicle. (This

is typically done to ensure a reliable vehicle arrival time.[1]) Many-to-many DRT systems have been implemented in such places as Greece (Rochester), New York; Haddonfield, New Jersey; and Merced, California.

Because a many-to-many system serves all points in a given area, it is not ideally suited as a feeder service, where passengers are brought to a single transfer point. Nevertheless, a many-to-many service can be used as a feeder service, with the transfer point serving as "one of many" drop-off locations. The Greece-Rochester system is an example of a system which operates in this fashion. (MIT, 1976) Passengers on that system can be asked to be taken to one of two locations where they can transfer to line haul buses. Passengers can also be picked up at the transfer points for the "distribution" trip. The context in which a many-to-many feeder system might be introduced is further discussed later in this chapter.

2.1.2 Many-to-One Cycled Service

In a "many-to-one" service, passengers are picked up at their door as in a many-to-many service, but all passengers are taken to a common destination (or vice versa). Thus, this type of system is better suited to a feeder service. In a cycled service (sometimes referred to as a discrete run time service), vehicles are constrained to leave the transfer point at regular intervals. Vehicles are routed through the service area, to drop off and pick up passengers, and then return to the transfer point in time for the next scheduled cycle.

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[1]The impact of this action will be discussed later on. Note that many DRT services for the elderly require all passengers to reserve in advance. In this way, it is hoped that the most efficient vehicle tours can be developed.

Because the cycle lengths can be set equal to the line haul vehicle headway (or an integer multiple of the headway), this type of service is ideally suited to the feeder mode. Passengers can be brought to meet every line haul vehicle (or, in low headway systems, every second or third vehicle) and passengers arriving on the line haul vehicle will have a feeder vehicle waiting for them when they arrive. This type of transfer mechanism is typically referred to as a coordinated transfer.

Cycled service is also much simpler to dispatch than a many-to-many system. Passengers requesting inbound (to the transfer point) service are simply placed on the next scheduled tour. (In cases where capacity is reached, passengers would be required to wait until the following tour.) Alternatively, passengers making advanced requests or standing orders would be placed on the tour leaving at approximately the correct time. Typically the driver is asked to determine the order of the stops, thus further reducing the duties of the dispatcher. Passengers desiring outbound service are never processed by the dispatcher; they simply board the feeder vehicle and tell the driver where they wish to be dropped off.

In part because the outbound trip destinations are not known in advance, service areas in a many-to-one cycled system are typically divided into small zones, each serviceable by only a few vehicles. Thus a passenger arriving at a transfer point would board a vehicle traveling to the zone in which the destination is located. This is the type of system operating in places such as Ann Arbor, Michigan, and Regina, Saskatchewan. Multiple vehicle operation in a single zone is discussed later in this chapter.

Note that in a many-to-one cycled service, it is also feasible to serve passengers who are not traveling to a transfer point, but are traveling <u>within</u> a zone. In Ann Arbor, for example, approximately 30% of all passengers are "many-to-many"

passengers in this sense, although this figure varies significantly (from 0% to over 50%) across zones.

Procedures for handling many-to-many requests, questions of area size and vehicle fleet size, and similar issues regarding system design will be discussed later in this chapter.

2.1.3 Many-to-One Subscription Service

In a "subscription" service, the demand-responsiveness of a many-to-one service is further restricted in time by requiring that all passengers reserve service on a standing basis. In this manner, regular "routes" are devised. From the passengers' point of view, this system maximizes reliability, by providing service each day at the same time. From the service point of view, by knowing all demands in advance, it is possible to optimize vehicle tours, (once each week or month, or whatever period is required by the subscription operation), thus maximizing achievable productivity.

Because a subscription service implies regular ridership, it is typically oriented to the work trip. As such, it would generally be offered during peak periods only. While most subscription services implemented to date have been home-to-work services, home-to-transfer point (or feeder) service is a potential application. In the Greece-Rochester DRT system, subscription service is oriented to a major employment center, but some passenger travel to transfer points located adjacent to that center.

2.1.4 Other Systems

The above three types of systems represent the most common form of feeder service implemented or proposed to date and, as such, are the ones analyzed in this manual. However, other types of DRT systems could conceivably serve as feeder systems.

For example, a many-to-one immediate response system combines the characteristics of the many-to-many and cycled services discussed earlier. Vehicles are dispatched on demand, but passengers can only be taken to/from a transfer point. The advantages of this over a cycled service are: (1) passengers might be picked up closer to call in time (since they needn't be placed in a scheduled tour) and; (2) vehicles will not have to travel to the transfer point if there is no demand to go there.[1] However, unless there is an alternative use for the vehicles, such as in a many-to-many service, this latter point would serve no advantage. Because of the simplicity of the cycled service dispatch requirements, because of the resulting coordinated transfers, and because of improved service levels, the cycled service is generally superior to a dynamic dispatch service. Thus a dynamic many-to-one feeder service does not make sense in most applications. Many-to-one advance request service, which differs from subscription service only in that tours may change from day to day, has been implemented in a number of locations, primarily to serve major elderly and handicapped activity centers. (U.S. DOT, 1974)

In a route deviation service, vehicles follow a route, but are free to deviate from the route to pick up and drop off passengers at their door on demand. This type of system has not been used in the feeder mode, but potentially could be used in that manner. Route deviation service can be reasonably approximated by fixed route service in network analysis and, as such, has not been considered in this manual.

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[1] This might be an advantage in a system where vehicles can be used in another service area zone. This type of service would also make more sense if the location served is a major activity center which has random, rather than scheduled, arrivals.

In a many-to-many checkpoint service, persons may be taken to or from any of the predetermined set of checkpoints located in an area. The concept behind this service is to limit the distance which each vehicle must travel (by eliminating the need to provide doorstep service to all passengers) while keeping walk distances acceptably small. By doing so, productivity can be increased, and travel time reduced. This type of service has been proposed, but has not yet been implemented in this country.

Similarly, in a many-to-one checkpoint subscription service subscribers are picked up at designated checkpoints, rather than at their door. In this manner productivities can be maximized. New subscribers can more easily be added to existing routes if they are able (and willing) to walk to an existing checkpoint. The Greece-Rochester home-to-work subscription service does have two checkpoint routes (and many school bus systems operate in this fashion), but checkpoint subscription feeder service has not yet been implemented.

2.2 System Design Guidelines

This section is intended to point out various system design parameters, and provide some guidelines regarding the conditions under which each of the systems analyzed is best implemented.

Many-to-many systems, by their nature, make most sense in areas with dispersed travel patterns. Systems of this sort have been implemented in areas of up to 20 square miles. Beyond that size it becomes very difficult to satisfy the diverse travel desires, unless there are many vehicles (30 or more) in operation. Areas of larger size could be broken into zones, where inter-zonal travel would require a transfer.

In a many-to-many system, feeder trips (to a line haul facility) would typically be handled as any other trip. If the line haul operates on long headways (20 minutes or more), it

might be desirable to ask feeder passengers to request service in advance so that an attempt can be made to deliver them to the transfer point only a few minutes before the scheduled line haul departure.

The distribution trip can be handled in a number of ways. The simplest is to have a passenger alighting from a line haul vehicle call for distribution service at that time. However, this results in a fairly long transfer delay for these passengers, which is not consistent with the philosophy of integrated feeder/line haul service. The alternatives are either to require passengers to call for DRT service before boarding the line haul vehicle or, preferably, to require them to request service <u>on board</u> the line haul, and have the line haul driver radio the control center with the request and the estimated time of arrival at the transfer point. In the Greece-Rochester system, the transfer procedure evolved from the first listed option to the last. Since it is desirable to send a DRT vehicle which is traveling in the appropriate direction, it is important to have the passenger give his/her destination address to the line haul driver. If this is not done, passengers on board this vehicle might receive very long ride times, and overall productivities could be reduced.

In most DRT systems, advance requests are effectively treated as higher priority demands; this would be the case particularly where transfering passengers are involved. In this case, it is desirable to minimize the transfer time to ensure coordinated transfers. By making an extra effort to serve these persons, it is conceivable that service levels of other passengers would be degraded. Simulation analyses have indicated that, as the percent of all trips which are advanced requests increases, total travel time for other passengers may increase by as much as 60%, depending upon area size and demand levels. Thus the benefits of coordinated transfers are offset, in part,

by disbenefits to other travelers. This trade-off is considered by the many-to-many supply model presented in this report.

Most many-to-many DRT systems implemented to date have been manually dispatched. Experiments with computer dispatching have been carried out in a number of locations, including Haddonfield, New Jersey and Rochester, New York. Both of these experiments have indicated that computer dispatching has the potential for improving level of service. Specifically, the evidence from the Haddonfield experiment suggested that a computer would decrease average passenger wait time (at a constant demand/productivity level) by about 40%, while the more recent experiment in the Rochester/Irondequoit service area indicated that a wait time reduction of about 50% could be achieved. In both cases, ride time was unaffected by computerization. The supply model presented in this report is based on a computerized DRT system, but incorporates adjustments for manual dispatching. As a general rule, systems with fewer than 10 vehicles would probably not benefit significantly from computerization, with the potential benefits increasing with vehicle fleet size and demand density.

The shape of a many-to-many service area is not a critical issue, although a compact, regular (i.e. convex) shape allows the most efficient routing. A transfer point located near the center of the zone in a multiple vehicle system would typically result in the shortest ride time to and from the transfer point. Note, however, that such a location would require that some passengers backtrack in order to reach the line haul system. This requirement would most likely limit demand for feeder service, and the impact would increase with service area size.

As a general rule regarding feeder service area design, consider that feeder service makes most sense when fairly long line haul travel times are involved. Persons making short line haul trips are likely to be unwilling to accept long feeder trips

and transfer delays. Since demand-responsive systems typically have longer ride times than fixed-route systems for the same length trip, this problem is intensified for DRT feeder systems.

A cycled many-to-one service, as noted earlier, is particularly well suited to the feeder role. The use of this type of service in such a capacity is closely tied with the concept of coordinated transfers; i.e., timing the arrival of feeder and line haul vehicles so that transfer delay is minimized or eliminated.[1]

To accomplish coordinated transfers, the "cycle time" of the many-to-one system should equal the line haul headway. In cases of very short headways of, perhaps, 5 minutes or less, this requirement might be relaxed, and a feeder vehicle scheduled to meet every other line haul vehicle. This is possible because the distribution transfer delay would still be very short.

To enable feeder vehicles to cycle through the service area in a period equal to the line haul headway, it is necessary to keep the service area very small. A maximum size of 4 square miles is probably a reasonable rule of thumb, with the actual maximum dependent upon demand levels and local traffic conditions. Larger areas can be broken into subareas to achieve this result, with different vehicles assigned to each subarea. As was the case for many-to-many service areas, these subareas should have fairly compact, regular shapes in order to maximize service levels and productivities.

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[1]Note that UTPS modeling does not allow for the representation of coordinated transfers, as it automatically calculates a transfer time equal to one-half the headway of the line haul route to which the transfer is being made. An approach to modeling coordinated transfers is discussed in Chapter 4.

If the size of the overall service area and the number of vehicles available are such that the vehicles cannot meet every line haul vehicle, even with the area divided into subareas, two modes of operation can be followed. In the first mode, termed in-phase operation, vehicles would be assigned to subareas, as above.[1] The vehicles would all be scheduled to arrive at the transfer point at the same time, to meet every second, third, or fourth line haul vehicle, whichever is feasible. In other words, under this option no attempt is made to serve every line haul vehicle, but an attempt is made to coordinate all feeder vehicles. Under this option, passengers arriving at the transfer point on a line haul vehicle not being met by a feeder vehicle would experience transfer delays equal to half the cycle time on average (where the cycle time is an integer multiple of the line haul headway). This delay could be avoided if the passenger information system is sufficiently developed such that passengers knew which line haul vehicle to take in order to meet a feeder vehicle. (Of course, in that case transfer delay would be replaced by "schedule delay", a concept which is discussed further later in this chapter.)

The second mode which can be followed is known as out-of phase operation. Under this mode, the feeder vehicles are not scheduled to arrive at the transfer point simultaneously. Instead, (at least) one feeder vehicle is scheduled to meet every line haul vehicle, with alternate feeder vehicles meeting alternate line haul vehicles. In this case, every feeder vehicle must cycle through the entire service area. Out-of-phase operation results in reduced inbound wait time (since vehicles cycle

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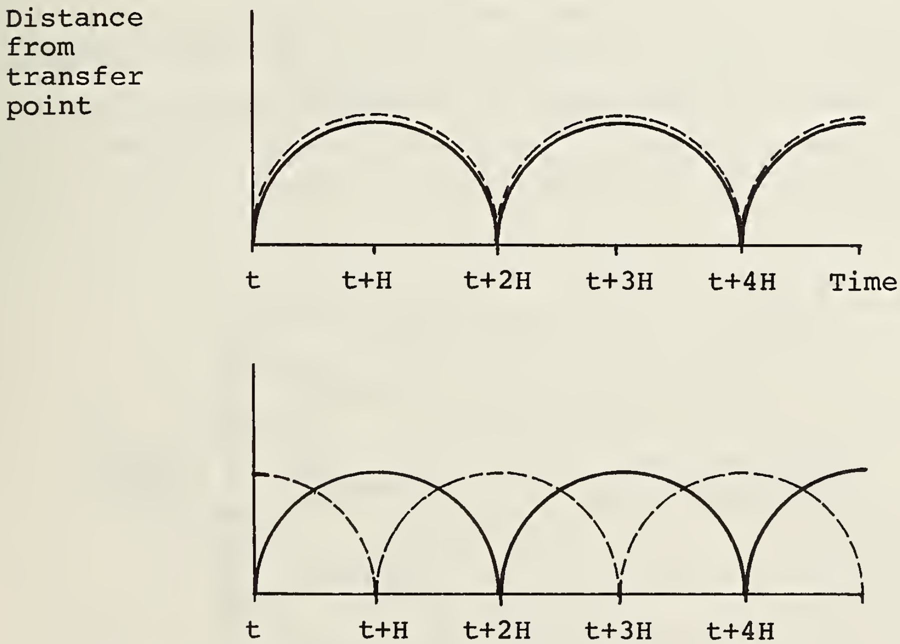
[1] There can be overlap between subareas.

through the area more frequently than under in-phase operation), but increased inbound and outbound ride times (since each vehicle covers a larger area). Some in-phase/out-of-phase tradeoff curves are provided in Appendix B. It should be noted that, as demand increases and capacity is reached, the out-of-phase wait time advantage disappears, since some passengers must wait until the next cycle to be picked up. At those points, in-phase operation becomes clearly superior.

To illustrate the difference between in-phase and out-of-phase operation, Figure 2.1 shows the distance of two vehicles (X and Y) from the transfer point, at the time of the arrivals of a number of line haul vehicles.



H = line haul headway

—— = Vehicle 1

--- = Vehicle 2

Figure 2.1

Distance of Feeder Vehicles
From Transfer Point as a Function of Time
(2-Vehicle System)

As was the case with many-to-many systems, a transfer point located near the center of the service area will typically result in better service levels than a transfer point near the periphery of the area. Because of the potential for subdividing the area and restricting vehicles to subareas, the potential impact of a central transfer point location are even greater. Again, however, the benefits of an internal transfer point may be, in part, offset by the requirement for some passengers to backtrack, as well as by the possible need to lengthen the line haul route.

In designing feeder service areas, it is conceivable that a choice will be necessary between a single and a multiple transfer point system. These options are illustrated in Figure 2.2. In the case of many-to-many service, a single transfer point may make most sense, since that reduces the total number of stops which must be made, hence maximizing productivity. (The area might be broken into 2 zones if it is too large for a many-to-many zone). In a cycled service, however, the

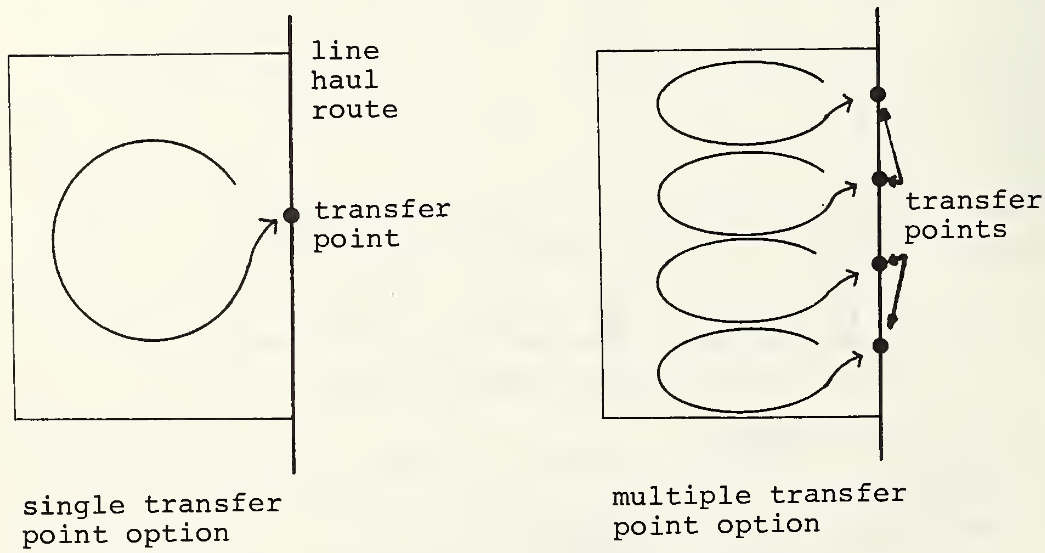


Figure 2.2
Feeder Service Area Options

tradeoff is similar to the tradeoff between in-phase and out-of-phase operation. In general, if the area can be divided into subzones in which transfers can be coordinated, the multiple transfer point strategy is generally best.[1]

Note that there is no requirement that the transfer points shown in Figure 2.2 actually be within the service area. Geographical considerations might be such that it makes sense to locate the transfer point beyond the service area boundaries. In such a case, the feeder service would have a short, external line haul segment to the transfer point. This option is considered by the model presented here, as discussed in a later chapter.

To help understand the modeling framework described in the next chapter, a cycled service can be thought of as having a collection phase, during which passengers heading to the transfer point are picked up, and a distribution phase, during which passengers picked up at the transfer point are dropped off. To minimize the length of a vehicle's tour, these two phases can be effectively combined, such that some passengers might be picked up during the distribution phase or others dropped off during the collection phase. (This, of course, would tend to increase ride times.) From a practical viewpoint, this approach is typically not followed; in Ann Arbor, for example, it was found easier for both the driver and dispatcher to consider the phases separately, although exceptions are made (Neuman et al, 1974). In the cases where the cycle time is longer than necessary, the separation of the collection and distribution phases enables the driver to remain idle for a few minutes before starting the collection tour; this has no impact on overall productivity, but serves to decrease inbound ride time.

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[1]This will depend upon: (1) the ability to locate more than one transfer point on the line haul without introducing substantial layover time and degrading service and; (2) the ability to communicate to the passengers the transfer point at which they should alight from the line haul in order to board the distributor vehicle traveling to their destination.

The way in which the collection/distribution phases are handled also impacts the way in which "many-to-many" passengers are served. To conform with a true division of the two phases, passengers who do not wish to be taken to the transfer point would be picked up during the collection phase, taken inbound to the transfer point, and taken outbound and dropped off during the distribution phase. This approach, which tends to increase the ride time of the "many-to-many" passenger is, in fact, followed in some cases in Ann Arbor. Alternatively, both the pick up and the drop-off could be made during either the collection or distribution phase.

Since many-to-many passengers can be handled in a cycled service, while feeder passengers can be handled in a many-to-many service, a logical question to ask is under what circumstance each of these systems should be implemented. Attempts were made to analyze a many-to-many service with a large percentage of feeder passengers and a cycled service with a large percentage of many-to-many passengers. Howevever, since the models being used were not calibrated on situations such as these, the results of this analysis are inconclusive. Some of the trade-offs between many-to-many and many-to-one cycled service are indicated in Appendix B. One simple guideline that might be followed would be to establish a many-to-many system if more than 50% of the passengers are expected to be many-to-many , and a cycled service if the majority are expected to be many-to-one passengers. However, given some of the advantages of cycled service, in terms of simplified dispatching, (thus eliminating the need for a computer), coordinated transfers, and the elimination of communication between line haul drivers and the DRT control center, cycled service probably makes most sense in situations where even 60-65% of the passengers are many-to-many passengers. Note that it may also be conceivable segment a vehicle fleet, operating some vehicles in a many-to-many mode and others in a many-to-one mode (if sufficient demand

of each type exists to justify the use of dedicated vehicles in this manner). Alternatively, a very realistic scenario might be to offer cycled service during peak hours, when a significant amount of demand will be oriented towards the transfer point, and switch to many-to-many service during the off-peak, when more point-to-point trips within the service are likely to be made.

Subscription service, as noted earlier, has most frequently been utilized to serve the work trip. For serving the feeder trip, subscription service is basically equivalent to a cycled service where all requests are standing orders. Subscription service can typically be more productive (passengers per vehicle hour) than cycled service, since requests are essentially known (for the length of the subscription period) rather than probabilistic, allowing more efficient tours to be developed. A subscription feeder service makes most sense during peak hours, when passengers make regularly occurring work trips. Note that, in most cases, these trips will be in one direction only; during the A.M. peak subscription service will consist of the collection tour only, while during the P.M. peak it will consist of the distribution tour only. One-way-only service is the type of subscription service considered in this manual. Once again, a common system design may have one type of DRT system, subscription, during the peak hours, and another type, many-to-many or cycled, during the off-peak.

Because all demands are known (and scheduled) in advance, and because the assignment of passengers to a bus effectively creates fixed routes operating in sub-areas, service area size is less of an issue for subscription service than for the previous services discussed. Subscription routes tend to develop along radial corridors, emanating from the transfer point(s). As was the case with cycled service, a multiple transfer point system, if feasible, will typically prove to be superior to a

single transfer point system.

The transfer point in a subscription feeder service can be located at any convenient point along the line haul route. A park and ride station may be a very suitable location. In a cycled service, on the other hand, an attempt should be made to locate the transfer point at a major activity center, such as a shopping center. In this way, non-regular, non-feeder trips (such as shopping) can be easily served by the feeder system. This points to the big difference between a subscription service and a cycled service. The former is intended to serve regular trips, such as the work trip, exclusively. The subscription nature of the service maximize reliability, i.e., the passenger can be fairly confident of being picked up and dropped off at about the same time each day. The cycled service can serve non-regular trips as well as regular trips. It is conceivable that, in a given area, subscription service can be provided during the A.M. peak to serve the work trip, with cycled service offered throughout the remainder of the day.

Since passengers in a subscription service are picked up at a regularly scheduled time, there is no "wait time" as there is for many-to-many or cycled service (where wait time is the time between the call for service and pick-up). Instead, wait time is replaced by "schedule delay," which can be defined as the difference between desired and actual departure or arrival time (i.e., the delay caused by not being able to travel at the desired time). Schedule delay can also be associated with conventional fixed schedule transit systems (particularly low frequency suburban sources); typically, however, schedule delay is ignored in most analyses. The way in which schedule delay might be considered in analyzing DRT systems is discussed briefly in Chapter 4.

3.

The DRT Service Models

Introduction

The models described in this report were developed during earlier research, but refined as part of the effort through which this report was prepared. The refinements were introduced to make the models more flexible and, in some cases, more accurate for certain ranges of input variables. References to the original models are noted in the sections describing each model.

This chapter is intended to provide the reader with a brief overview of the DRT feeder models considered. Included are descriptions of all important model inputs and outputs. The models are described more fully in Appendix A.

3.1 Many-to-Many Service Model

The many-to-many model[1] is a descriptive model consisting of a set of equations which predict mean wait time (WT, defined as the time between the call for service and the arrival of a vehicle) and ride time (RT, the actual time spent by a passenger on board a vehicle). Mean ride time for both many-to-many passengers and feeder passengers (who typically have a different average trip distance) are calculated.

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[1]The model was originally developed in an earlier phase of this project. A full description of the model development can be found in: Lerman, et al,(1977) and Flusberg and Wilson (1977).

The model also computes total travel time (TT, the sum of wait and ride times) for both types of passengers.

The basic inputs to the model are:

- Demand rate (passenger trips per hour)[1]
- Service area size (square miles)
- Load, unload time (minutes) (i.e., the time it takes to pick up and drop off a passenger).
- Mean trip length, many-to-many <u>and</u> feeder trips (miles)
- Mean vehicle speed (miles per minute)
- Average number of vehicles in service
- Street network adjustment factor (ratio of street distance and airline distance).

The model form was developed through observation of the relationship between service levels and these parameters, in both actual systems and simulation experiments. Bounds on system values were derived analytically. The model was calibrated with a simulation model which was developed by MIT and validated with data from the Haddonfield, New Jersey and Rochester, New York DRT systems. The model has since been incrementally extended to include a number of factors which were not directly considered by the simulation experiments. The initial model considered only a computerized dispatched system operating with all immediate request passengers. The revised model has factors to adjust for:

- Manual dispatching
- Wait time/ride time trade-offs created by different dispatching objectives
- The impact of vehicles going in and out of service
- The impact of advance requests on passenger service levels.

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[1]The software developed for this and all subsequent models actually enables the user to specify a minimum and maximum demand rate and will estimate level of service for all specified demand increments.

Although the calculation of transfer time is a necessary element in the use of the models in the UTPS framework, transfer time is not a direct output of the model. Since coordinated transfers should probably be assumed for the line haul to DRT trip, transfer time can essentially be set as an input. This is discussed further in Chapter 4.

3.2 Many-to-One Cycled Service Model

The many-to-one cycled service model[1] consists of a set of equations which predict the expected inbound wait time for all passengers, outbound wait (transfer) time, inbound ride time for feeder (collection) passengers, outbound ride time for distribution passengers, and ride time for many-to-many passengers. The equations were derived analytically, based on an assumed dispatch strategy under which vehicles proceed from each stop to the next nearest point. Basic model inputs include:

- Demand rate (passenger trips/hour)
- Percent of demands which are many-to-many
- Percent of demands which are inbound many-to-one (collection)
- Percent of many-to-many demands served entirely on inbound portion of vehicle tour
- Percent of many-to-many demands served entirely on outbound portion of vehicle tour
- Layover time at transfer point (minutes)
- Line-haul distance outside service area to transfer point (miles)
- Base vehicle speed (miles per minute)

[1]The model as initially developed is described in Daganzo, et al, (1977). The model was refined and expanded in the course of this project.

- Street network adjustment factor
- Cycle time of DRT vehicles (minutes)
- Size of service area (square miles)
- Load, unload times (minutes)
- Number of vehicles
- Headway of DRT vehicles at transfer point (minutes)
- Location of transfer point (on circular service area boundary, in center of service area, external to service area).

To develop estimates of service levels, a vehicle tour is considered to consist of the following components:

1. Rendezvous time: The time from the last pickup of one cycle until the first drop-off of the next. (Includes layover time.)

2. Distribution time: The time from the first drop-off of an outbound passenger until the last drop-off of an outbound passenger.

3. Deadhead time: The time from the last drop-off outbound until the first pick-up inbound.

4. Collection time: The time between the first and last pick-ups inbound.

Rendezvous time is calculated as the layover time, plus the time to get from a random point in the service area (representing the last stop on the collection tour) to the transfer point, plus the time to get from the transfer point to a random point, (the first stop on the collection tour). This is based on the assumption that vehicles always proceed to the next closest point (and hence the collection tour need not end at the closest point to the transfer point). This algorithm does not result in optimal tours, but does represent a realistic situation in which drivers will be required to order the stops on each run. Collection time and distribution time are both calculated, based on a derived formula for estimating the expected distance between a given point and the closest of n random points. Average inbound ride time is then calculated as one-half the collection time plus

the "collection line-haul" portion of the rendezvous time (end of collection tour to transfer point), while the average outbound ride time is calculated as the distribution line-haul plus one-half the distribution time. Wait time is estimated through a queing relationship developed in DeNeau (1976). Level-of-service estimation is described in more detail in Appendix A.

3.3 Subscription Service Model

The subscription service model is an analytically derived model which computes expected service levels for subscription passengers. Outputs of the model include mean ride time (in both directions), schedule delay, and transfer time. The computerized version of the model will also automatically indicate at what demand level service becomes infeasible for a given vehicle fleet size. Specific model inputs are:

- Demand rate (demands per hour) to be considered
- Number of vehicles
- Headway of DRT vehicles at transfer point (minutes)
- Cycle time of feeder service (minutes)
- Length of service area along X-axis (miles)
- Length of service area along Y-axis (miles)
- Base vehicle speed (miles per minute)
- Load, unload times (minutes)
- Layover time at transfer point (minutes)
- Seating capacity of feeder vehicles
- X,Y coordination of transfer points (miles)

The model's algorithm is based on the subdivision of the service area into sectors, with one vehicle assigned to each sector. The vehicle tour is divided into the following components, illustrated in Figure 3.1.

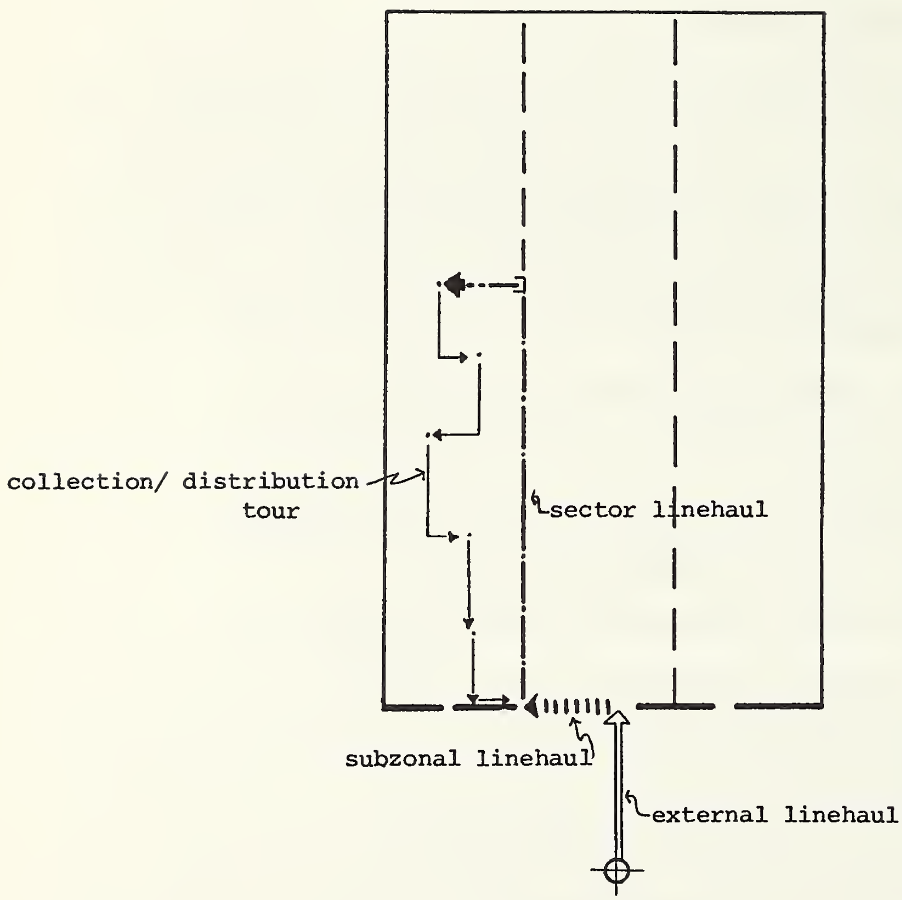

Figure 3.1
Subscription Service Tour Components

- External line-haul (if any) - the distance from the line-haul station to the closest service area boundary point

- Service area line-haul - the distance from the service area boundary point to the nearest corner of a sector

- Sector line-haul - the distance from the corner of a sector to the first (furthest) pickup, or last (furthest) drop-off

- Collection/distribution tour - the tour taken by the vehicle between the first and last pick-up or drop-off points.

The first three components are derived directly from geographic considerations. The fourth component is derived from simulation analysis which utilized a traveling salesman algorithm. (Mason and Mumford (1972).[1]

The vehicle tour time estimate is used to determine whether the vehicle can make the tour within the given cycle time. Average passenger ride time is computed as half the collection/distribution tour, plus the service area and external line-haul times.

Note that if the transfer point is located within the service area and not along the boundary, the model automatically segments the area into separate sub-zones such that the transfer point ends up on a boundary, as shown in Figure 3.2.[2]

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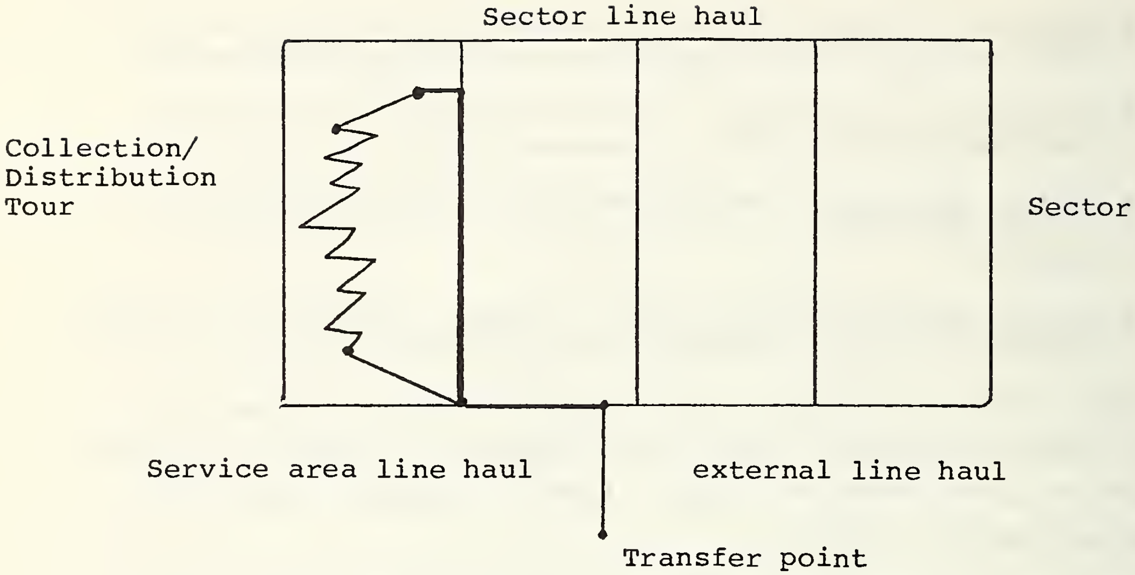
[1] The model utilized in this report is a refined version of model which is based on this reference, but has gone through a number of modifications in previous studies. Other references are Batchelder et al (1976) and D. Ward (1975).

[2] If one of the resulting sub-zones becomes too small to justify the use of one vehicle, the transfer point is effectively moved such that either: (1) the smaller zone disappears entirely (i.e., the transfer point is moved to an outside boundary, thus creating only one zone, when the sub-zone is too small to support even ½ a vehicle) or: (2) the zone is enlarged to allow for one vehicle (i.e., the transfer point is moved closer to the center of the service area when the sub-zone is large enough to support more than ½ but less than 1 vehicle).



Subscription Vehicle Tour Components

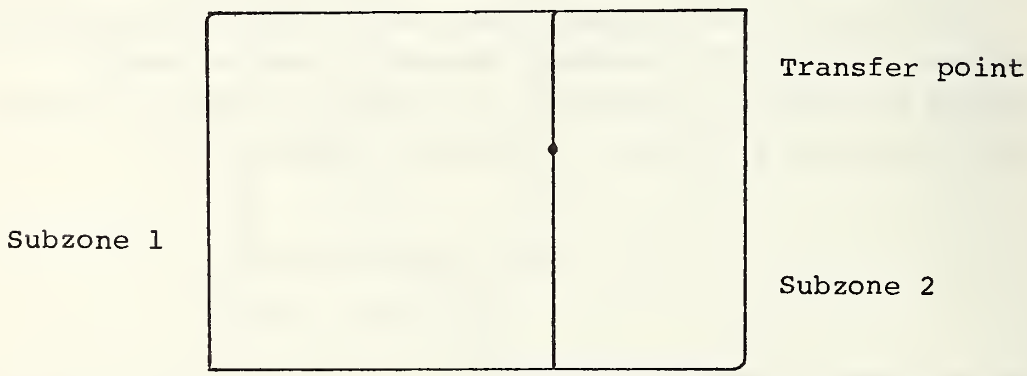


Figure 3.2
Subscription Service Area Subdivision

4.

Application of the Models Within the UTPS Framework

Introduction

In this chapter, the way in which the DRT feeder service model outputs can be used within the UTPS context is explored. On the simplest level, these models provide the UTPS user, for the first time, with the tools necessary to estimate DRT feeder service access times. Such estimates can play a role in transit network design. The analysis of DRT services as part of an overall transit network demand analysis, however, complicates the UTPS modeling process, since DRT service levels are highly sensitive to demand. A procedure for dealing with this complication is discussed later in this chapter.

Note that the DRT supply models can also be used as "stand-alone" tools to explore various intra-zonal DRT system design options. This application is not explicitly discussed in this report, which deals specifically with UTPS applications. However, it should be recognized that the availability of DRT service models provides added flexibility in using UTPS to analyze possible future transit networks. For example, the models can be used to explore the impacts of reducing the size of the fixed route transit network and instituting DRT service areas. As noted in Chapter 1, one possible future transit scenario would call for an extensive fixed route network during peak hours, complemented by a set of DRT feeder zones in outlying areas, with a sparser fixed route network and expanded DRT zones introduced in the off-peak to accommodate a greater number of local, off-peak trips.

The description of the models themselves, and the discussion in this chapter, should provide the UTPS-user with sufficient information to analyze situations of this type.

4.1 Calculation of Access/Egress Times

First of all, DRT feeder service is treated as an access mode, in much the same way as the walk or the auto mode. The DRT models are used to compute the access and egress time for a given feeder system.

For example, a typical application of the models might involve the situation depicted in Figure 4.1. DRT feeder service is to be provided in Zone 51, with transfers to a line haul system occurring at "node 232." Consider first the question of access time, or the time it takes the average person to get to the transfer point. (Egress time is the travel time in the reverse direction, which is not necessarily the same.) Access time on a DRT system to a line haul station consists of the following components:

1. In-vehicle time, i.e., ride time
2. Out-of-vehicle time, i.e., wait time or schedule delay plus transfer time

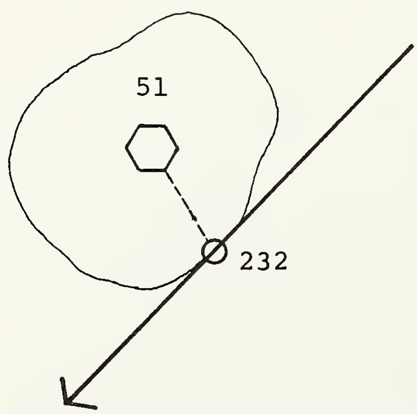


Figure 4.1
Feeder Zone Representation

As noted in the previous chapter, these quantities (with the exception, in some cases, of transfer time) are the outputs of the supply models. Specifically, ride time is predicted as the in-vehicle travel time component for all three models. Wait time is the out-of-vehicle component for many-to-many service, and schedule delay is the out-of-vehicle component for subscription service, while either time is predicted for cycled service (wait time for immediate request passengers and schedule delay for advanced request passengers).

Transfer time for both cycled service and subscription service is determined by layover time, which is a system design (input) variable.[1] Layover time is established in the transit system to allow time for the transfer of passengers from the feeder vehicle to the line haul vehicle and vice versa. The length of the scheduled layover should be set to allow for variations in arrival time of both the line haul and feeder services. Thus layover time is a function of reliability. For very short headway (line haul) systems (e.g., less than ten minutes) layover time can be set relatively short (e.g., one minute), since missed connections would not result in serious delays. For longer headways, however, the variability of line haul and feeder arrivals must be more closely considered. In lieu of actual arrival variability data, a layover time equal to 10% of line haul headway, with a minimum of one minute (to perform necessary transfers) and a maximum of five minutes, is suggested.

For a many-to-many system, a coordinated transfer would probably <u>not</u> be guaranteed, since the arrival of feeder vehicles at transfer points is not scheduled. Thus for many-to-many systems, transfer time might be calculated as one-half the line-haul headway, with a maximum specified, if so desired. Note

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[1]Transfer time is calculated as one-half the layover time.

that in UTPS (UPATH), a wait time is automatically calculated as one-half the headway for all transit lines used. For many-to-many service, this wait time is equivalent to the feeder to line haul transfer time. Thus, in that case, there is no need to separately estimate transfer time.

Considering first a many-to-many system; access link time, or A, is the weighted sum of wait time and ride time. Specifically (using selected UTPS notation):

$$A = RUN(F) \times T(F) + WAIT(F) \times I(F)$$

where:

RUN(F) is a (UTPS user-supplied) weight on run, or ride time for the DRT feeder mode (F);

T(F) is the calculated run or ride time;

WAIT(F) is a (UTPS user-supplied) weight on wait time; and

I(F) is the out-of-vehicle or "idle" time; in this case the wait time

The user could employ the same weights supplied for fixed route conventional transit modes. Alternatively, since wait time for feeder service is wait time spent at home rather than at a bus stop, the user may wish to specify a different set of weights for feeder service wait time.[1] Note that these (feeder service) weights are never entered into UTPS runs; rather, they are used externally in the above equation to calculate access time, which is then input as part of the network description. The feeder service acess time would be entered as the access time for one of the three allowable UTPS non-transit modes.

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[1]Previous research into DRT service level impacts suggest that wait time at home is no more onerous for DRT passengers than is ride time. This is in sharp contrast with the prevailing rule of thumb for conventional transit, where wait time is assumed to be at least 2.5 times as onerous as ride time. (Golub and Gustafeson, 1971)

Next consider the estimation of access link time for a many-to-one cycled service (assuming for the moment that all passengers are immediate request passengers and thus see an actual wait time). Note that UTPS will automatically calculate transfer time as one-half the line haul headway, even though in this case it is assumed that there are coordinated transfers (and a transfer time is output by the feeder supply model). UPSUM, the program which extracts impedance values from the paths, has the capability of separating out the "first" wait time, which in this case is the transfer time to the line haul mode, from all subsequent wait (transfer) times. If the programs being used allow the "first wait" time to be ignored for all zones served by a DRT feeder system, (after tree skimming, or, preferably, in the demand model), there is no need to consider transfer time further. If this capability is not available, it is suggested that compensation for this transfer time be built into the access time. Thus access link time A for many-to-many cycled service is calculated as:

$$A = \mathrm{RUN(F)} \times \mathrm{T(F)} + \mathrm{WAIT(F)} \times \mathrm{I(F)} + \mathrm{WAIT(L)} \times \mathrm{R(F,L)} - \mathrm{WAIT(L)} \times \left(\frac{\mathrm{HD}}{2}\right)^{1}$$

where:

WAIT(L) is the user supplied weight on line haul wait time;

R(F,L) is the feeder to line haul transfer time calculated as one-half the layover time;

HD is the line haul service headway (or twice the maximum allowable transfer time if a maximum has been specified) and

All other variables are as before.

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[1] UTPS also allows the inclusion of a transfer penalty (ADD(M)), which can be incorporated in this equation if desired.

In the above equation, the last term is the transfer time compensation, which should be left out if the first wait time can be zeroed out.

Finally, consider the case of subscription service (which is identical to the case of advance request passengers on a cycled, many-to-one service). Again a transfer time compensation factor may need to be introduced. The only difference between this system and the cycled service in terms of calculating access time is that schedule delay replaces wait time as an out-of-vehicle time component. Thus access link time in this case might be calculated as:

$$A = RUN(F) \times T(F) + SCHD(F) \times S(F) + WAIT(L) \times (R(F,L) - \frac{HD}{2})$$

where:

SCHD(F) is the weight placed on schedule delay;

S(F) is the schedule delay = one-half the cycle length; and

All other variables are as before.

There has been very little research concerning the impacts of schedule delay, and on how heavily schedule delay would be "weighted" in comparison with actual wait time. Frequently, schedule delay simply is ignored, i.e., SCHD(M) is assumed to equal 0. Thus the user might wish to ignore this factor for the purposes of analyzing subscription service. If the user does desire to represent schedule delay in some fashion, a range of values of SCHD(F) = .3 x WAIT(F) - .8 x WAIT(F) is suggested; i.e., schedule delay might be considered 30% to 80% as onerous as wait time. Note that, if schedule delay is being weighted to the same extent as transfer time for line haul service (i.e., if SCHD(F) = WAIT(L), and if the cycle time is equal to the line haul headway, the automatically computed transfer time component of access link time will be equal to the schedule delay component. In this case, these components will simply cancel out; there would be no need to explicitly include the transfer time compen-

sation if the schedule delay component itself is ignored.

Next consider egress time, which is the time spent on the DRT system <u>after</u> transferring from a line haul feeder vehicle. UTPS allows access/egress time to be input separately, one representing the time spent traveling in one direction in a given zone, and the other time spent traveling in the opposite direction. Egress time for the three DRT modes would be calculated as follows:

For many-to-many service:

$$E = RUN(F) \times T(F) + WAIT(F) \times K$$

where:

E = egress time;

K = input expected transfer time, if "outbound" transfers are treated as advanced requests resulting in coordinated transfers. A value of K in the range of two to three minutes, representing feeder vehicle arrival uncertainty is suggested; and

Other variables are as before

For many-to-one cycled <u>or</u> subscription service:

$$E = RUN(F) \times T_{out}(F) + WAIT(F) \times R(F,L) + WAIT(L) \times (FH-HD)$$

where:

$T_{out}(F)$ = ride time in outbound direction;

FH = headway of feeder vehicles, i.e., the time between arrivals of successive feeder vehicles at the transfer point. FH is equal to the cycle time for in-phase operation, but it is shorter than the cycle time for out-of-phase operation.

Other variables are as before.

Note that this formulation takes into account the additional transfer time created when feeder vehicles do not meet every transfer vehicle. FR should equal HD in cases where at least one feeder vehicle meets each line haul vehicle; in these cases the last term in the above equation equals 0. If one wishes to assume that passengers will have perfect information and choose only those line haul vehicles that connect with a feeder vehicle, the

last term in the equation should always be excluded. In those cases, however, a schedule delay term (SCHD(F) x $\frac{FH}{2}$) should be substituted for this term.

4.2 Incorporating Feeder Services in the UTPS Framework

The previous section described the way in which the DRT feeder model results are used to estimate access and egress time by DRT; these values are then used as inputs to the UTPS network description. In this section the way in which DRT services can impact the overall UTPS analysis framework is discussed.

This discussion is included largely because of certain problems introduced by considering DRT services. First, unlike the case for conventional fixed route services, DRT service levels are particularly sensitive to demand levels.[1] Thus it becomes critically important to be able to compare the output results of any demand analysis based in part on DRT service levels with the demand values used as input to the service level prediction process. Compounding the problem is the necessity to be able to estimate in some manner the "sub-modal split"[2] between feeder and auto (and walk) access in a given zone to be able to input the

---

[1] To be able to estimate DRT service levels, even in feeder systems, it is necessary to know the intra-service area DRT demand as well. This demand can probably be ignored in the case of many-to-one service geared largely to the feeder trip. For many-to-many service, however, where feeder trips are likely to constitute only a small portion of total trips, the estimate of intra-zonal demand is crucial. At least one demand model for demand-responsive transportation is available (Lerman et al, 1977). In lieu of this, the analyst wishing to consider many-to-many service would have to develop some other methodology for estimating many-to-many demand.

[2] Used in this context, sub-modal split refers to the split of the transit demand to/from a given zone between all possible access modes.

DRT feeder demand level. These problems are not new; a rigorous analysis of conventional fixed route service can also require sub-modal split estimation and a number of iterations. However, the nature of DRT service tends to place greater emphasis on the solution of these problems.

While this report is not intended to provide detailed solutions to UTPS modeling and representation problems, some suggested procedures for avoiding new problems created by modeling DRT services are appropriate. These procedures are probably best considered in the context of a typical UTPS modeling application. Such an application, dealing with transit network analysis, might involve the following steps[1]:

1. Transit network building (UTPS program UNET)
2. Pathfinding (UPATH) and impedance matrix building (UPSUM)
3. Addition of intra-zonals (UMCON, UMATRIX)
4. Mode split estimation (UMODEL)
5. Assignment (ULOAD)

The output of this process is an estimate of the loads on all links in the transit network. The output can be used to determine whether changes in the network are required; in general, however, unless capacity constraints are violated there would be no need to recompute transit network input parameters.

In analyzing a transit system which has DRT feeder elements, an initial estimate of DRT demand is required in order to compute access and egress times. These values are used as input to the network (step 1 above). Following the modal split estimation (step 4), plus some <u>sub</u>-modal split estimation, an estimate of DRT feeder demand would be obtained. It is highly likely that this estimate will not be consistent with the initial estimate

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[1]These steps assume the input of a regional trip table.

used as input. The revised demand estimate would change the DRT access/egress times, which could potentially impact both network impedances and transit mode split. Thus there must be some method for reconciling input and output. The suggested procedure would involve the following steps, illustrated in Figure 4.2[1]

1. Given a known or assumed volume of trips originating in (destined to) a particular zone, estimate the potential market share of the DRT system (i.e., transit share of trips to (from) all other zones x DRT share of access (egress) trips). For this analysis, the analysis zones must be aggregated to the DRT service area level.

2. Decide the number of DRT vehicles to input per zone, recognizing that DRT systems typically average 5-10 demands per vehicle per hour, (although subscription services may achieve productivities up to 20 passengers per vehicle per hour).

3. Use the appropriate graphical results in Appendix B or the appropriate supply model to estimate wait and ride times.

4. Calculate DRT access/egress time as described in Section 4.1[2] and enter the access links into the network.

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[1]This procedure assumes an identification of the zones with DRT service as part of the initial network description.

[2]The user may wish to develop a composite access link which accounts for all access modes, including walking and auto. Care must be taken to avoid the "bus paradox" problem which arises from the situation in which feeder bus (fixed route or DRT) service is introduced in a zone previously served only by auto access. If access time is computed as the "average" of the different access modes, overall zonal access will be worsened (since bus level of service is almost always worse than auto level of service), when in fact it should be improved by the addition of feeder service; the result of this would be a lower estimate of transit modal share. One approach used to avoid this problem is to consider only a "composite" auto link, and add decreasing penalties penalties to the base access time as alternative choices are added. Referring to the case of DRT service, the lower the estimated access time, the smaller the penalty. An alternative approach to measuring accessibility which borrows from consumer choice theory, is suggested in Ben-Akiva and Lerman (1977).

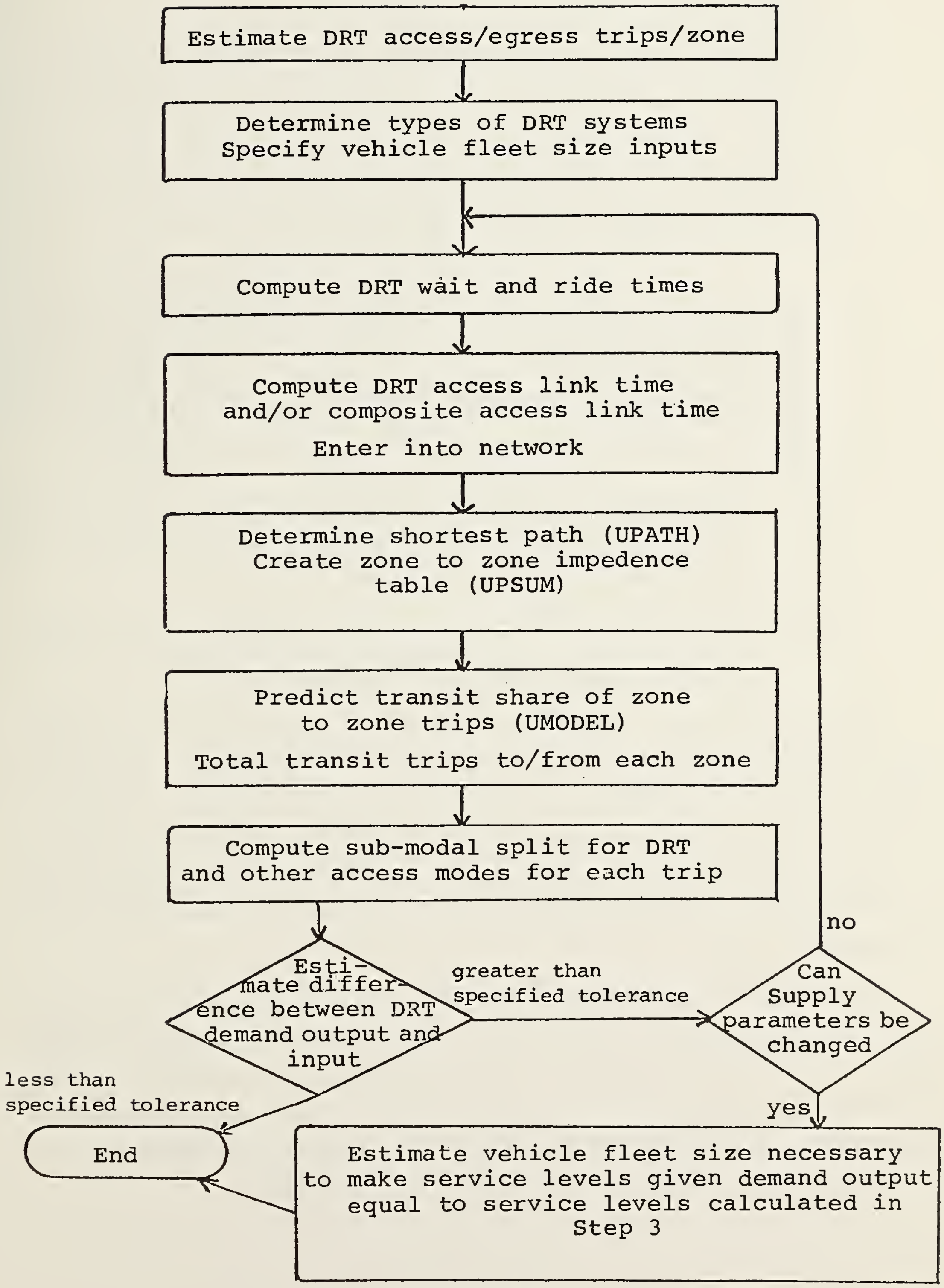

Figure 4.2
Steps in UTPS Analysis with DRT Access Modes

Given: Trip table; Zones with DRT service

5. Run UPATH to determine the shortest paths through the transit network, and UPSUM to create tables of zone to zone impedances.

6. Through UMODEL, use whatever demand model is normally applied to estimate zone to zone transit mode split. For each zone in which transit DRT feeder service exists, compute the total number of access and egress trips.

7. Compute the expected submodal split by auto, DRT, and any other access modes. Analysts can select any appropriate sub-modal split analysis tool.

8. Compare the predicted DRT feeder access service demand with the assumed demand. If the difference is within a selected tolerance limit (perhaps ± 10%), the analysis related to the DRT system can cease. If the difference is sufficiently great such that the potential impact in access/egress time is expected to alter the results of steps 5-8, the following two options are available:

    a. Modify the DRT vehicle fleet estimates (using Appendix A or B of this manual) such that the access and egress times given the demand found in step 8 approximate the values used in step 3.

    b. Re-estimate DRT and composite access/egress time given the new DRT demand values, and repeat all successive steps (3-8) until convergence.

As noted above, in order to be able to estimate access and egress times on a DRT feeder system it is necessary to know the demands on the DRT system. Given total zone to zone transit volumes, it is therefore necessary to estimate the percentage of all trips originating in and ending in a given zone, which use the DRT system. This percentage is known as the sub-modal split or share for DRT.

In a regular application of UTPS, the user may wish to measure sub-modal share of the walk, feeder, and auto access modes. However, given the relative insensitivity of fixed route feeder service characteristics to demand there is less of a necessity to perform a sub-modal split analysis. Thus, most UTPS users will not have a submodal split routine available.

The problem of sub-modal split in the UTPS context is receiving considerable attention. The reader is directed to the forthcoming "UMODEL Users Guide, Case Studies on Access Representation" for a treatment of this subject. For the user considering the adaptation of existing demand models for use in sub-modal split analysis, it should be noted that a disaggregate demand model for demand-responsive transportation has been developed. The reader is directed to Lerman, et al. (1977) for a complete description of that model.

APPENDIX A
DETAILED MODEL DESCRIPTIONS

A.1 Many-to-Many Model

A.1.1 Basic Equations

The many-to-many model is the simplest of the three models, consisting of a set of equations that are easily solved. Consider first the basic equations for estimating wait, ride, and travel times:

Wait time: $$WT = \frac{f_a}{2V_{eff}} \sqrt{\frac{A}{VEH}} \quad \exp\left(k_1 \sqrt{\frac{A+4}{VEH+12}} \quad \lambda^{k_2}\right) \qquad [A-1]$$

where:[1]

WT = mean wait time for all passengers except those transferring from line haul to DRT.

f_a = street network adjustment factor.

V_{eff} = the effective vehicle speed including stops, computed as:

$$V_{eff} = \frac{(60 - (\ell + u)\lambda)V}{60} \qquad [A-2]$$

where ℓ, u = load, unload time (minutes)

V = vehicle speed (miles/minute)

λ = vehicle productivity = $\frac{D}{VEH}$

[1]Since the three models discussed in this appendix were developed by different groups at different times, variable names and other convention differ. It was decided to use the original specification, rather than develop a uniform set of nomenclature. Since all variable names are defined, this should not pose a serious problem.

D = demand rate (trips/hour)[1]

VEH = vehicle fleet size (average number of vehicles in service)

A = service area size[2]

k_1 = constant, set to .219 for systems with vehicle capacity >5 and set to .20 for systems with vehicle capacity $\leq$5 (e.g., shared-ride taxi)

k_2 = constant, set to .9 for systems with vehicle capacity >5 and set to 1.0 for systems with vehicle capacity $\leq$5

$$\text{Ride time} = RT(m) = \frac{f_a \, DD(m)}{V_{eff}} \exp\left(.0843\left(\frac{A\lambda}{VEH}\right)^{.7}\right) \qquad [A\text{-}3]$$

where:

RT(m) = ride time for intra-service passenger area [RT(i)] or feeder passengers [RT(f)]

DD(m) = average trip length for passenger being considered

DD(i) = passenger trip length for intra-service area passengers

DD(f) = average trip length for feeder passengers

all other variables as before.

Travel time: TT = WT + RT [A-4]

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[1] When modeling real world situations, the analyst may wish to take into account "no shows", i.e. passengers who request service but are not there when the vehicle arrives. Various DRT systems have experienced no show rates ranging from 2-20%. The impact of no shows can be partially considered by treating no shows as "half-demands" (i.e. pick-ups only). In actuality, no shows have a greater impact than simply adding an extra stop, since tours are developed around expected drop-off points which which would also not be made.

[2] The many-to-many model was developed for square service areas, the many-to-one model for circular areas, and the subscription model for rectangular areas. Simulation experiments have indicated that area shape does not have a significant impact on service levels, except in cases of extremely irregular shapes. Nevertheless, the user should be aware of the conditions for which the model was developed.

Note that in the case of ride time, no distinction is made based on vehicle capacity. Note further that these equations behave properly as bounds are approached, namely:

- as $\lambda \to 0$: RT approaches direct (auto) ride time =

  $$\frac{f_a DD(m)}{V_{eff}}$$

  WT approaches expected travel time between a point and the closest of VEH randomly distributed points in area A

  $$WT \to \frac{f_a}{2V} \sqrt{\frac{A}{VEH}}$$

- as $\lambda \to \infty$: $WT \to \infty$; $RT \to \infty$
- as $A \to \infty$: $WT \to \infty$
- as $VEH \to \infty$: $WT \to \infty$, $RT \to \infty$
- as $VEH \to \infty$: $WT \to 0$, $RT \to$ direct ride time

A.1.2 Default Values

To help utilize these models, the following suggestions are offered:

- f_a is computed as the ratio of average street network distance to straight airline distance between two points. A perfectly rectangular grid system has an adjustment factor of $4/\pi$ or 1.273. Data from a number of cities suggest that most areas probably fall into the range 1.2 - 1.4 (Wilson et al., 1976). A default value of 1.273 is suggested.
- A base vehicle speed of around .25 miles per minute is probably reasonable in most cases, although clearly local conditions will have a significant impact.
- Values of ℓ in the range of .75 to 1.75 minutes and u in the range .4 to 1.25 minute are probably appropriate, with systems serving many elderly passengers experiencing values in the upper end of this range.
- The demand rate of importance is trips per hour, rather than passengers per hour. If it is assumed that some passengers will travel together (same origin and destination), total passenger estimate should be divided by average expected group size (a range of 1.1 to 1.3 is standard) for input to the model.

- For service areas that are not too large (e.g., less than 25 sq. mi.), a good approximattion for DD(i) can be made by $.53\sqrt{A}$ (the mean airline distance between two randomly distributed points in an area of size A, given that no trip is less than .2 miles). The mean distance to the transfer point, DD(f) for transfer points at the edge of the service area, can be approximated as the direct distance between the edge and the center of the zone. For transfer points at the center of the zone, the approximation $.39\sqrt{A}$ (airline distance) can be used.

A.1.3 Model Adjustments

The first adjustment made to the model was intended to adjust for situations in which vehicles are scheduled to enter and leave the system through the course of the day. At a certain time prior to the scheduled end of shift, a vehicle scheduled to leave service will no longer be assigned new passengers. Thus, although that vehicle is still in service, as far as passengers waiting for pickup are concerned, there is one less vehicle available. The result is that mean wait time is higher than it would be in cases where vehicles remain in service constantly. (Wilson, 1975) Preliminary analysis suggested the use of an "effective vehicle fleet adjustment factor" (FAF) in calculation of wait time. Each time VEH appears, in the wait time equation only (including the calculation of productivity and effective vehicle speed) it is multiplied by FAF. A default value of .85 for FAF is suggested; the actual value is a function of the number of times vehicles enter and leave service and the location of the relief point, but no function of this type has been developed. If the analysis is of a very short period of time, when the vehicle fleet is assumed to remain constant, the FAF term can be ignored (i.e., FAF = 1.0).

The second model adjustment was designed to account for the difference between a manual and computerized dispatch system. The base model was developed for a fully computerized system. Data from the two sites in which fully computerized dispatching has been achieved, Haddonfield, New Jersey and Irondequoit/Rochester,

New York, indicated that computer dispatch results in a reduction of wait time, but no change in ride time. In Haddonfield, wait time decreased by 20%; in Irondequoit, it decreased by 40%. The suggested adjustment is straightforward:

$$WT_m = (1 + \alpha)WT \qquad [A-5]$$

where:

WT_m = mean wait time for manual dispatching

α = an input adjustment factor

A range of α = .25 to .75 is suggested by the two data points. α can be expected to increase with productivity, but there is no data to support that hypothesis at this time. A default value of .5 is suggested.

The two final adjustments also relate to dispatch strategies. Simulation analyses have indicated that the lowest overall travel time is obtained if wait time and ride time are treated (weighted) equally when making passenger assignments. (Wilson et al., 1976) The base model was calibrated using a dispatching algorithm that made this assumption. It has been noted, however, that human dispatchers tend to weight ride time more heavily, since they perceive passengers on board vehicles, but not those waiting at home, as "on the system." Furthermore, drivers, even under computer control, have a tendency to perform drop-offs ahead of scheduled pick-ups in order to satisfy passengers already on board. (Flusberg and Wilson, 1976) While not seriously impacting total travel time, this results in different wait time and ride times than predicted by the base model. Analysis has indicated, however, that different weights on wait and ride time change wait and ride time significantly, but change total travel time by 10% at most. Using the assumption that the total travel time does not vary at all, a "wait time/ride time tradeoff" adjustment factor has been proposed. This adjustment can apply to computer-dispatched systems if wait and ride time are not weighted equally. However, it is more likely to apply to a manually dispatched system. Expanding Equation [A-5], the values for adjusted wait time (WT_a) and ride time (RT_a) are given by:

$$WT_a = [1 + \alpha + \beta]\ WT \qquad [A\text{-}6a]$$

$$RT_a = RT - BWT \qquad [A\text{-}6b]$$

$$TT_a = WT_a + RT_a \qquad [A\text{-}6c]$$

where β is in the range -.6 to +.6; negative for cases where wait time is weighted more heavily than ride time and positive in the more common case where ride time is weighted more heavily than wait time.

Empirical data suggest that a in the range .3 to .5 will explain the difference between model prediction and actual manually dispatched systems (for $\alpha = \phi.5$). β can be expected to increase with area size and trip distance. Note that equation A-6b could theoretically result in a mean ride time smaller than the direct ride time. The computer program listed in Appendix C tests for this condition and uses direct ride time as a lower bound.

The final adjustment is intended to account for the fact that, in most systems, advanced request passengers are effectively treated as higher priority passengers. Vehicle resources are "saved" to ensure that advanced request passengers are picked up on time. The result is a degradation of service for other passengers. (Note that the same result is likely any time there are different passenger priorities). The impact is likely to be very small in systems operating below capacity (which have vehicle slack), but increases with increasing productivity. Simulation experiments were used to verify this assumption, and estimate a simple function relating the impact to the percent of passengers who are advanced request and to system productivity. The adjusted model is of the form:

$$TT^{o} = TT_a + \Delta TT \qquad [A\text{-}7a]$$

where:

TT^{o} is the adjusted travel time

ΔTT is the change in travel time given by:

$$\Delta TT = \gamma TT_a \qquad [A\text{-}7b]$$

where:

$$\gamma = 4.3\ PADV^{.8764} \left(\frac{\lambda}{\lambda+2}\right)^{6.219} \qquad [A\text{-}7c]$$

where:

PADV = fraction of passengers which are advanced requests.

λ = productivity (unadjusted for effective vehicle size)

ΔTT was found to be distributed more heavily on wait times than ride time, such that:

$$WT^o = WT_a + .65\Delta TT \qquad [A\text{-}8a]$$

$$RT^o = RT_a + .35\Delta TT \qquad [A\text{-}8b]$$

where:

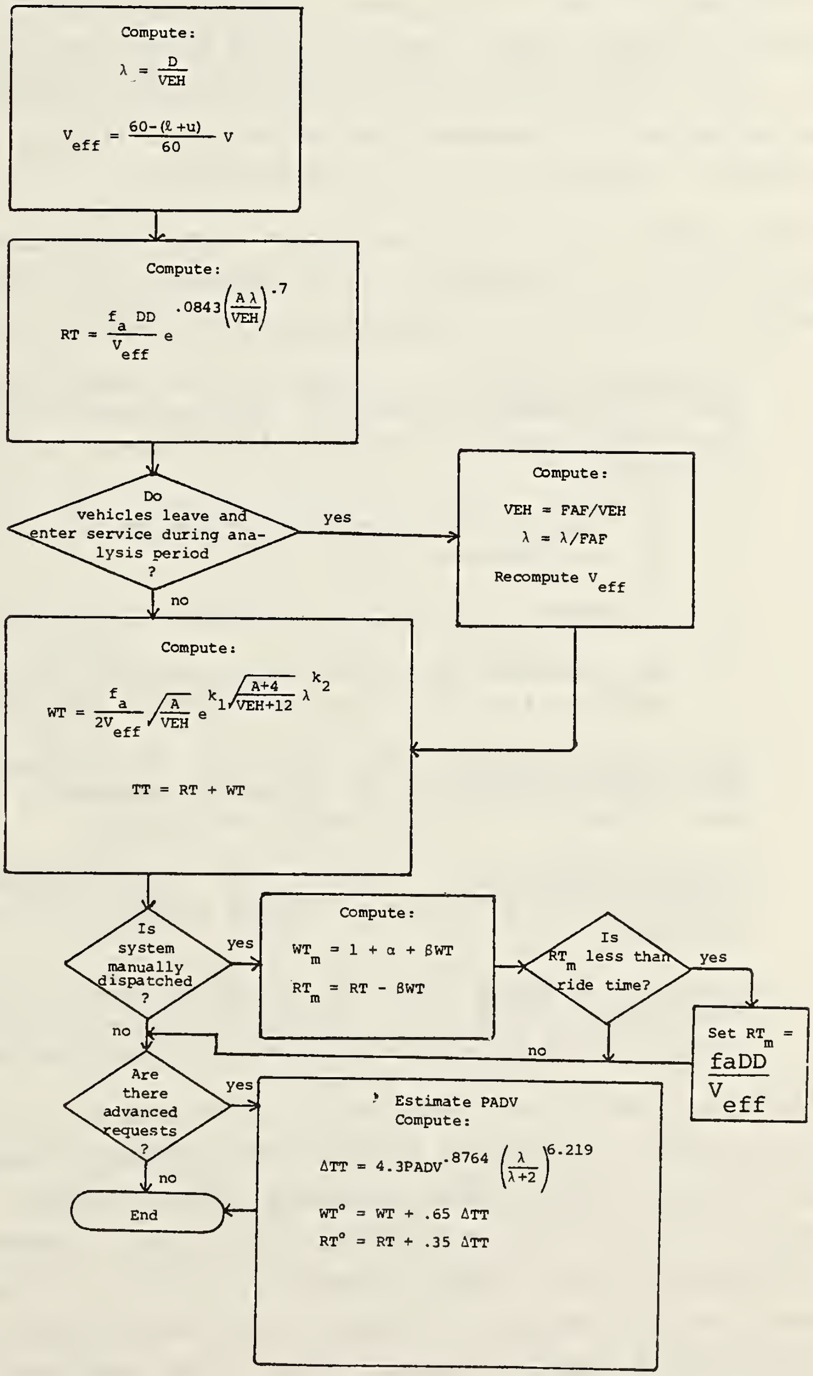
WT^o and RT^o are the final adjusted wait and ride times

WT_a and RT_a are the previously computed values for either manual or computer dispatch.

The many-to-many model can easily be applied using a hand calculator that can exponentiate. The series of steps to be followed in using this model are illustrated in Figure A.1.

Figure A.1

Steps for Running Many-to-Many Model



A.2 Many-One Cycled Service Model

A.2.1 Vehicle Tour Components

The many-to-one cycled service model is based on work performed by Hendrickson, Daganzo, and Wilson at MIT. (Daganzo et al., 1977) Modifications have been made to expand the scope of the model and to improve the accuracy of the model predictions for services operating at low productivities.

The many-to-one cycled services model calculates service characteristics by determining the length of time necessary to perform the following components of a vehicle's tour.

1. Rendezvous Time (L): This is the travel time from the last inbound pickup in the current cycle through the first outbound dropoff in the next cycle, which includes

   a. An inbound link from a random point in the zone to the transfer point (L_1).

   b. A layover time at the transfer point (L_2).

   c. An outbound link from the transfer point to the destination of a random outbound passenger (L_3).

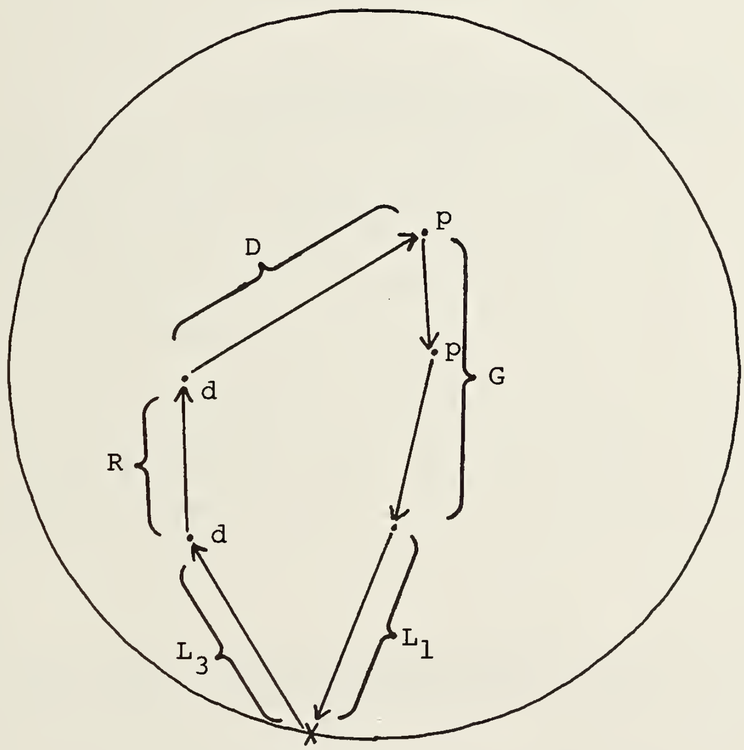
2. Distribution Phase (R): This is the travel time from the first dropoff of an outbound passenger to the last dropoff of an outbound passenger.

3. Deadhead Time (D): This is the time from last dropoff of outbound passenger to first pickup of inbound passenger.

4. Collection Phase (G): This is the travel time from the first pickup of an inbound passenger to the last pickup of an inbound passenger during the cycle.

The components are illustrated in Figure A.2. To evaluate these components, effective inbound and outbound demand rates, average vehicle speed, pickup/dropoff (load, unload) times, and transfer point layover time must be input. Demand rates are a function of the overall demand level and the distribution of demand between inbound, outbound, and many-to-many trips. The outbound and inbound demand rates, LAMA and LAMB respectively,

Figure A.2
Many-To-One Cycled Service Tour Components



can be directly calculated if all passengers riding the DRT system go to or come from the transfer point. Inclusion of many-to-many patrons will be discussed later. Important variables in the determination of component tour times are the average numbers of stops each vehicle makes during the inbound and outbound portions of its tour. The number of stops in the outbound (LMCA) and inbound (LMCB) portion of the tour depends on the demand rate, cycle times (C), and number of vehicles (VEH) as specified by the following equations:

$$LMCA = LAMA * C/VEH \qquad [A-9a]$$

$$LMCB = LAMB * C/VEH \qquad [A-9b]$$

A.2.2 Calculation of Rendezvous Time

The inbound rendezvous time (L_1) is the time required to travel to the transfer point from a random point within the service area. If the transfer point is outside the service area, this time includes an external line haul component (which is a constant equal to the travel distance divided by the speed on the linehaul links). It can be shown (Larson, 1972) that the internal portion of the rendezvous time is simply proportional to the square root of the area. The proportionality constants for travel from an edge of a circular area and from the center of a circular area are indicated in the following equations:

$$L_1 = .638r\sqrt{A}/V + LH + PT \qquad [A-10a]$$

for a transfer point located on the edge of the service area or external to it, or

$$L_1 = .376r\sqrt{A}/V + PT \qquad [A-10b]$$

for a transfer point located in the center of the service area.

where:

A = service area size (square miles)

V = base vehicle speed (miles/minute)

LH = linehaul time from transfer point to service area (minutes)

PT = pick-up (load) time

r = street network adjustment factor ($1.2 < r < 1.4$)

In these equations, airline distance is adjusted by a street network factor (r) and divided by the velocity to obtain the internal rendezvous time.

Transfer point rendezvous time (L_2) is simply the layover time (LO) built into the vehicle tour to assure reliable service. This is a design (input) variable which is a function of DRT and fixed-route service reliability. A good default value is 10% of the DRT vehicle headway, but not less than 1 minute nor greater than 5 minutes.

The outbound rendezvous time (L_3) is calculated in exactly the same manner as the inbound rendezvous time, or:

$$L_3 = (.638r\sqrt{A}/V + LH + DT) \qquad [A\text{-}11a]$$

for external or edge transfer point, or

$$L_3 = (.376r\sqrt{A}/V + DT) \qquad [A\text{-}11b]$$

for central transfer point.

where:

DT = dropoff (unload) time

The entire rendezvous time L is the sum of the three components,

$$L = L_1 + L_2 + L_3 \qquad [A\text{-}12]$$

A.2.3 Calculation of Distribution Tour Time

The distribution tour of this model is based on the stragegy that a vehicle proceeds from each stop to the next nearest passenger destination. The average distance between stops is approximated as $.505r\sqrt{\frac{A}{n}}$, where n is the number of passengers still on board the vehicle.[1] The total distance to drop off all passengers is therefore:

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[1] The distance between a point and the closest of n randomly distributed points in an area of size A. See Kendall and Moran (1963).

$$P = \sum_{n=1}^{N} .505r\sqrt{\frac{A}{n}} \qquad \text{[A-13a]}$$

where:

N is the total number of persons to be delivered.

Equation A-13a assumes that there is an integer number of demands to be delivered. To approximate this value over a stochastic range of dropoffs, Daganzo et al. (1977) developed an approximate continuous function which adjusts for the stochastic nature of the demand and the concave nature of the travel time function. The resulting equation for the distribution time (R) is:

$$R = P_d[(LMCA/P_d - 1)DT + 1.01r\sqrt{APV}\left(\Delta_a\sqrt{LMCA/P_d} - 0.5 - \sqrt{0.5}\right)/V] \qquad \text{[A-13b]}$$

where[2]:

$$\Delta_a = 1 - \frac{LMCA/P_d - 1}{8(LMCA/P_d)^2} \qquad \text{[A-14]}$$

$$APV = A/VEH * C/HDWY \qquad \text{[A-15]}$$

P_d = probability of having outbound demands to deliver:

$$P_d = 1 - e^{-LMCA} \qquad \text{[A-16]}$$

Note that $LMCA/P_d$ is simply the average number of dropoff stops, given that the number of dropoffs minus 1 (number of distribution tour links) is greater than zero.

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[1] Δa compensates for the stochastic nature of the arrivals and the concave shape of the tour time function.

APV is the area each vehicle must serve. It is assumed each vehicle serves an area of equal size and the formulation of the distribution tour distance is applicable to the sector served by the vehicle.

A.2.4 Calculation of Collection Tour Time

The collection tour time (G) depends on the size of the pool of passengers waiting to be picked up. As the system gets crowded, it is assumed that a backlog of passengers begins to build. These passengers are collected according to the "next nearest stop" strategy employed in the distribution tour. In this manner, the capacity of the system can be extended beyond that which would be achieved if a "first in/first out" (FIFO) operations strategy were employed. The passenger pool will reach an equilibrium level such that the system will remain in steady state. Note that the operating strategy assumed here may not be followed in all actual systems. As a result, this model is not necessarily valid for situations in which the pickup pool size significantly exceeds the number of inbound requests each vehicle can serve (at this point, a FIFO strategy is more likely to be followed).

The length of time required for a vehicle to travel from the last dropoff to the transfer point depends on how densely the passengers to be picked up are distributed throughout the service area. As the size of the pickup pool ($X^{*\prime}$, the number of people waiting to be picked up) increases, the collection time decreases. In the continuous deterministic case, the steady state pool size occurs when the sum of the collection and deadhead times are exactly equal to the time remaining in the cycle after the rendezvous and distribution times have been removed. In the stochastic case, the pool size must be slightly higher than this to account for the integer nature of demands and the variability in the actual pickup pool size from cycle to cycle. The theoretical justification of pickup pool size ($X^{*\prime}$) calculation is too complex to present in this text. Interested readers are directed to Daganzo et al. (1977). The value of the pool size is described by the following equation A-17 . Equations specifying intermediate results used in this equation are presented in the subsequent functions.

$$X^{*\prime} = X^{*} + \max\,(0,\ LMCB - Y^{\prime}) \qquad [A\text{-}17]$$

where:[1]

$$Y' = X^* - (X^* - Y)\ \phi\ \left(\frac{X^* - Y}{\sqrt{Y}}\right) - \sqrt{Y}\ \Phi\ \left(\frac{X^* - Y}{\sqrt{Y}}\right) \qquad [A\text{-}18]$$

$$Y = LMBC + \max\ (0,\ K - \sqrt{LMCB + 0.5}) + \sqrt{0.5} \qquad [A\text{-}19]$$

$$X^* = \max\ [0,\ (.5 + LMCB - K^2)/2K]^2 + LMCB \qquad [A\text{-}20]$$

$$K = (C - L - R - LMCB*BG)/ALP \qquad [A\text{-}21]$$

Given the pickup pool size, the probability of having at least one patron to collect is:

$$P_c = 1 - e^{-X^{*\prime}} \qquad [A\text{-}22]$$

This form is valid when the pool size ($X^{*\prime}$) is equal to the number of collections a vehicle must make on each tour. It results in a small underestimation at higher values of pool size, but recall that the model is, in general, less valid in this range as a result of the unrealistic pickup decision rule described above (i.e., a next closest stop rather than FIFO strategy).

The average collection tour time (G) is calculated conditional on the probability of having a pickup to make (as was the distribution tour time). The functional form of the collection tour time is similar to the functional form used to calculate the distribution tour time. The total distance between N pickups out of a pickup pool size $X^{*\prime}$ is:

$$P = \sum_{n=X^{*\prime}-N}^{X^{*\prime}} .505 \sqrt{\frac{A}{n}} \qquad [A\text{-}23]$$

This form is modified slightly to account for the variability of demand over time and the integer nature of demand, resulting in the following equation for the collection tour time:

$$G = P_c[(LMCB/P_c - 1)PT + \frac{1.01c}{V}\sqrt{APV} \qquad [A\text{-}24]$$

$$(\Delta_b \sqrt{X^{*\prime}/P_c - 0.5} - \sqrt{\frac{X^{*\prime} - LMCB}{P_c}})]$$

---

[1]Insert "ϕ" and "Φ" refer to the probability density and cumulative density functions of the standardized normal distribution.

where[1]:

$$\Delta_b = 1 - \frac{X^{*'}/P_c - 0.5}{8\ (X^{*'}/P_c)^2} \qquad [A\text{-}25]$$

PT = pickup time

A.2.5 Calculation of Deadhead/Down Time

The vehicle deadhead/down time (the idle time spent between the distribution and collection tours) is calculated as the time remaining in the available tour (cycle) time after the rendezvous, collection, and distribution phases have been subtracted. The value of the deadhead time is always greater than the minimum time required to travel between last drop-off and first pick-up of a vehicle's tour. This is assured during the calculation of the steady state pickups pool size. Deadhead time is calculated as

$$D = C - (L+G+R) \qquad [A\text{-}26]$$

A.2.6 Calculation of Level of Service

The level-of-service components are calculated in the following manner.

Outbound wait time (WTO) is the average amount of time that the passenger spends at the transfer point between the arrival of the fixed-route vehicle and departure of the DRT vehicle. Since DRT vehicles have a scheduled departure time, WTO is a function of only the fixed-route arrival time. The model assumes the fixed-route arrival is uniformly distributed across the DRT layover time. Thus, wait time is calculated as one half the layover time, or:

$$WTO = L_2/2 = \text{transfer time}^2 \qquad [A\text{-}27]$$

The inbound wait time (WTI) calculation is based on Little's formula which states that the number of customers in the queue

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[1]Again Δ is a term to adjust for the concave slope of the collection time function and the stochastic nature of inbound demands. This factor is only approximately correct for $X^{*'} > LMCB$

[2]This also equals the inbound transfer time.

equals the product of the customer arrival rate and the average waiting time (Little, 1961). The customer arrival rate is LAMB. The average queue length (L) is a function of pool size and is calculated with the following equations (Deganzo et al., 1977):

$$L = \left[\frac{X^{*\prime}\ (DRHDWY)^2}{(VEH)(C)} - \frac{(DRHDWY)^2\ (LAMB)}{2} + \frac{(G)(DRHDWY)(LAMB)}{2}\right] / DRHDWY \qquad [A-28]$$

Inbound wait time (at home) is then calculated as:

$$WTI = \frac{(X^{*\prime})(DRHDWY)}{LMCB} - \frac{DRHDWY}{2} + \frac{G}{2} \qquad [A-29]$$

Inbound ride time (RTI) is computed by considering that the average passenger travels for one half of the collection tour, plus the entire inbound linehaul, as shown in equation A-30.

$$RTI = L_1 + G/2{*}P_c \qquad [A-30]$$

Finally, outbound ride time (RTO) is similarly computed, or:

$$RTO = R/2{*}P_d + L_3 \qquad [A-31]$$

A.2.7 Inclusion of Many-to-Many Passengers

Many-to-many passengers are included in the cycled service model by adjusting the inbound and outbound demand rates to include these passengers. Each many-to-many passenger is included as two demands in the calculations of the effective demand rates, one for the pickup and one for the dropoff. These patrons can be served in one of three ways:

- Picked up and dropped off on the inbound portion of the vehicle's tour;
- Picked up and dropped off on the outbound portion of the vehicle's tour; or
- Picked up on the inbound portion of the tour and dropped off on the outbound portion of the tour.

If more than one vehicle operates in the service area at a single time, a many-to-many patron must have both origin and destination in the same vehicle sector to be served in either of the first two methods. The following formulas specify how the adjustments are made to the arrival rates to include many-to many patrons in this manner.

$$PSI = SI * C/VEH/HDWY \quad [A-32]$$

$$PSI = SO * C/VEH/HDWY \quad [A-33]$$

$$PIMTM = PMTM * (1 + PSI - PSO) \quad [A-34]$$

$$POMTM = PMTM * (1 + PSO - PSI) \quad [A-35]$$

$$LAMA_{adj} = (PO + POMTM) * DEM/60 \quad [A-36]$$

$$LAMB_{adj} = (PI + PIMTM) * DEM/60 \quad [A-37]$$

where:

C = DRT vehicle cycle time

VEH = number of DRT vehicles

HDWY = headway of fixed route service

SI = portion of many-to-many demands served entirely on the inbound portion of a tour if both origin and destination are served by the same vehicle.

SO = portion of many-to-many demands served entirely on the outbound portion of a tour if both origin and destination are served by the same vehicle.

PSI = portion of many-to-many demands served entirely on the inbound portion of a vehicle's tour.

PSO = portion of many-to-many demands served entirely on the outbound portion of a vehicle's tour.

PMTM = portion of total demand which are many-to-many

PO = portion of demands which are many-to-many outbound

PI = portion of demands which are many-to-many inbound

DEM = total demands per hour

$LAMA_{adj}$ = outbound demand rate (adjusted) in demands/minute

$LAMB_{adj}$ = inbound demand rate (adjusted) in demands/minute

The wait time for many-to-many passengers is the same as that for inbound passengers. Ride time for a many-to-many passenger (RTM) depends on how that person was carried. If the individual was carried on only one portion of the vehicle tour, then the ride

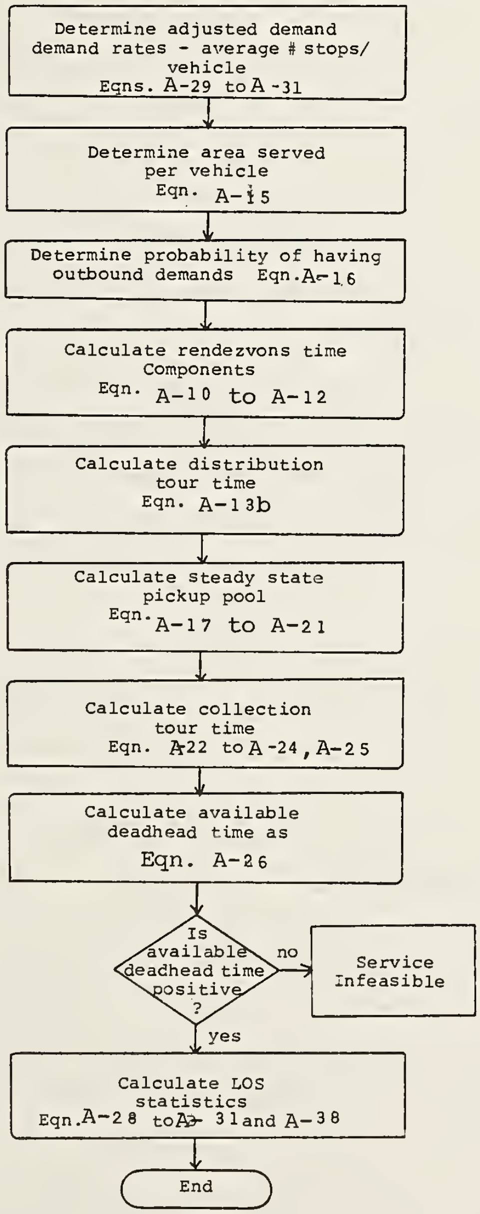
time is either one third that portion of the vehicle tour or the minimum average distance between two points within a sector, whichever is greater. If the passenger is carried past the transfer point, the average ride time is the sum of inbound and outbound ride times plus the layover time at the transfer point. The weighted sum of these ride times is:

$$RTM = (1 - PSO - PSI)(RTO + RTI + L_2) + PSI * \max(G/3, \frac{.505r}{V}\sqrt{APV} + PSO * \max(R/3, \frac{.505r}{V}\sqrt{APV}) \quad [A-38]$$

The steps involved in using the many-to-one cycled model are described sequentially in Figure A.2.

Figure A.3

Many-to-One Cycled Service Flow Chart



A.3 Subscription Service Model

A.3.1 Service Area Description

The subscription service model, based on work of Mason and Mumford (1971), Ward (1975), and Batchelder et al. (1976), determines service characteristics by assigning vehicles to sectors of the service area and calculating individual portions of a vehicle's tour. The times required to perform each of the elements of the tour are then combined to determine feasibility of service under the prescribed conditions and the resulting level of service received by the passengers.

The first step in modelling subscription service is to define the geography of the service area. A rectangular shaped service area is assumed, but the transfer point may be located at an arbitrary location, either internal or external to the service area. Figure A.4 illustrates the definitions of service area descriptors.

Given the service area description, the first portion of each vehicle tour can be defined. The external linehaul (DLH) portion of each vehicle tour is the absolute value of the distance from the transfer point to the nearest point in the service area. (Rectangular distances are used.) In Figure A.4, the external linehaul distance equals YLOC. If the transfer points were located below and to the left of the service area [at (-XLOC, -YLOC) where -XLOC and -YLOC are both less than zero], the external linehaul is XLOC + YLOC. Of course, if the transfer point is located within the service area, the external linehaul distance is zero. The location of the point at which vehicles enter and leave the service area is (XENT, YENT).

The next step in defining vehicle tours is to divide the service area into sectors, each served by only one vehicle. The number of sectors required depends on the total vehicle fleet size, the headway of fixed-route vehicles met by DRT vehicles, and the total time available for a DRT vehicle tour. The number of sectors is (SECT) is given by:

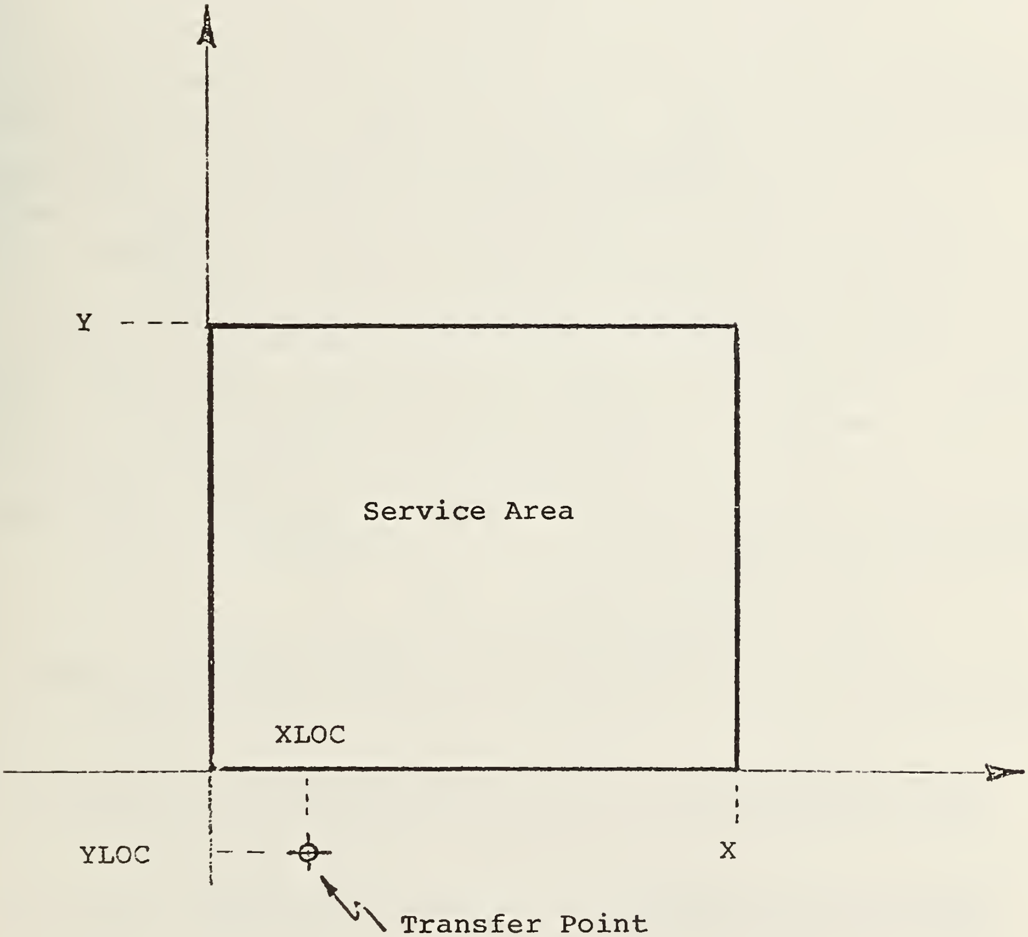


Figure A.4

Service Area Dimensions

$$SECT = VEH * \frac{HDWY}{CYCLE} \qquad [A-39]$$

where:

VEH = vehicle fleet size

HDWY = headway of fixed route vehicles

CYCLE = DRT vehicle tour time

If the transfer point is within the service area (i.e., not on a boundary), it is necessary to divide the service area into two subzones with a line through the transfer point running parallel to the shortest dimension of the service area. (See Figure A.5.) Sectors are then established such that the number of sectors in each subzone is proportional to the area of the subzone. If one of the subzones contains less than one full sector (i.e., cannot justify the operation of one full vehicle), it is either expanded to include a full sector (if originally there was "more than half" a sector), or eliminated (if originally there was "less than half" a sector). At this point in the analysis, there will be either one or two subzones to analyze. Each must be analyzed separately as described below.

A.3.2 Vehicle Tour Elements

The elements of the vehicle's tour that must be calculated for each of the existing subzones, shown in Figure A.6, are:

- Subzonal linehaul - the tour covering the average distance from the point at which the vehicle enters the service area to the nearest point of its assigned sector.

- Sector linehaul distance - the tour covering the distance from the point at which the vehicle enters its sector to the farthest pickup.

- Collection/distribution tour - the tour from the first pickup to the point at which the vehicle leaves the sector.

The calculation of the subzonal linehaul distance (DL) is based on the location of the transfer point, the number of sectors in the subzone, and the width of the subzone. Figure A.7 illustrates definitions used in this calculation. First, the sector in which the vehicle entry is located is determined.

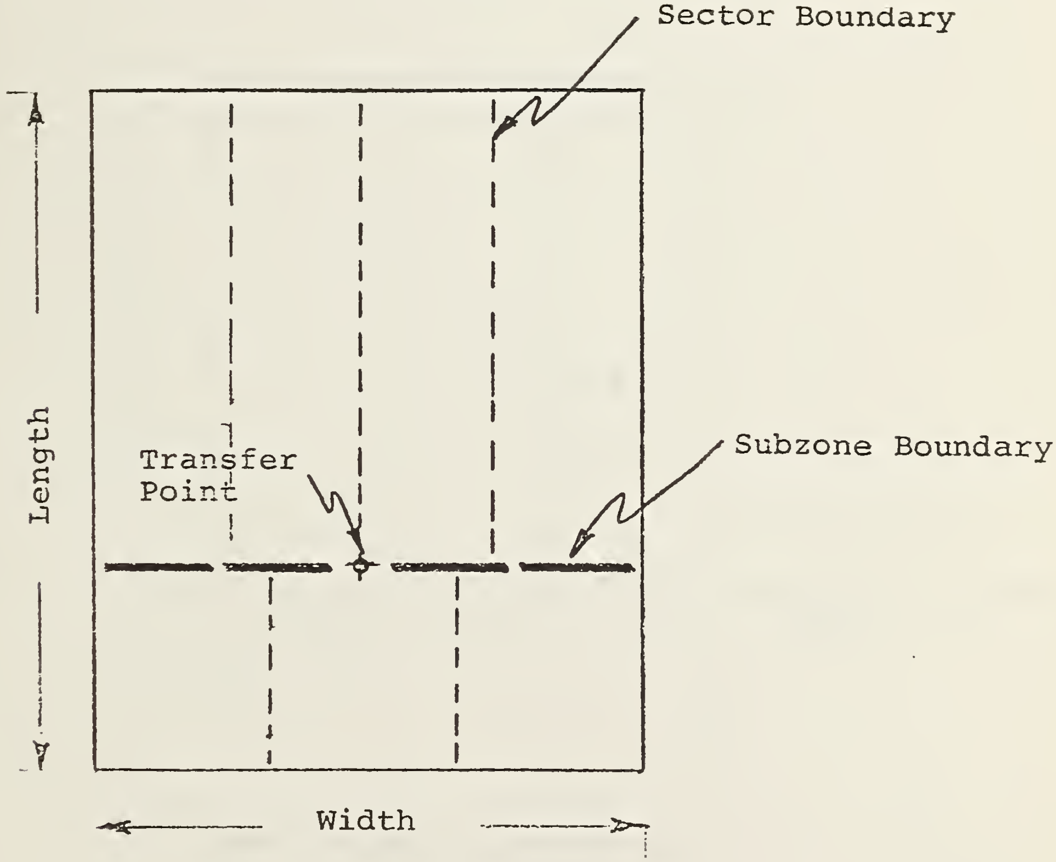


Figure A.5

Division Of The Service Area
For Internal Transfer Points

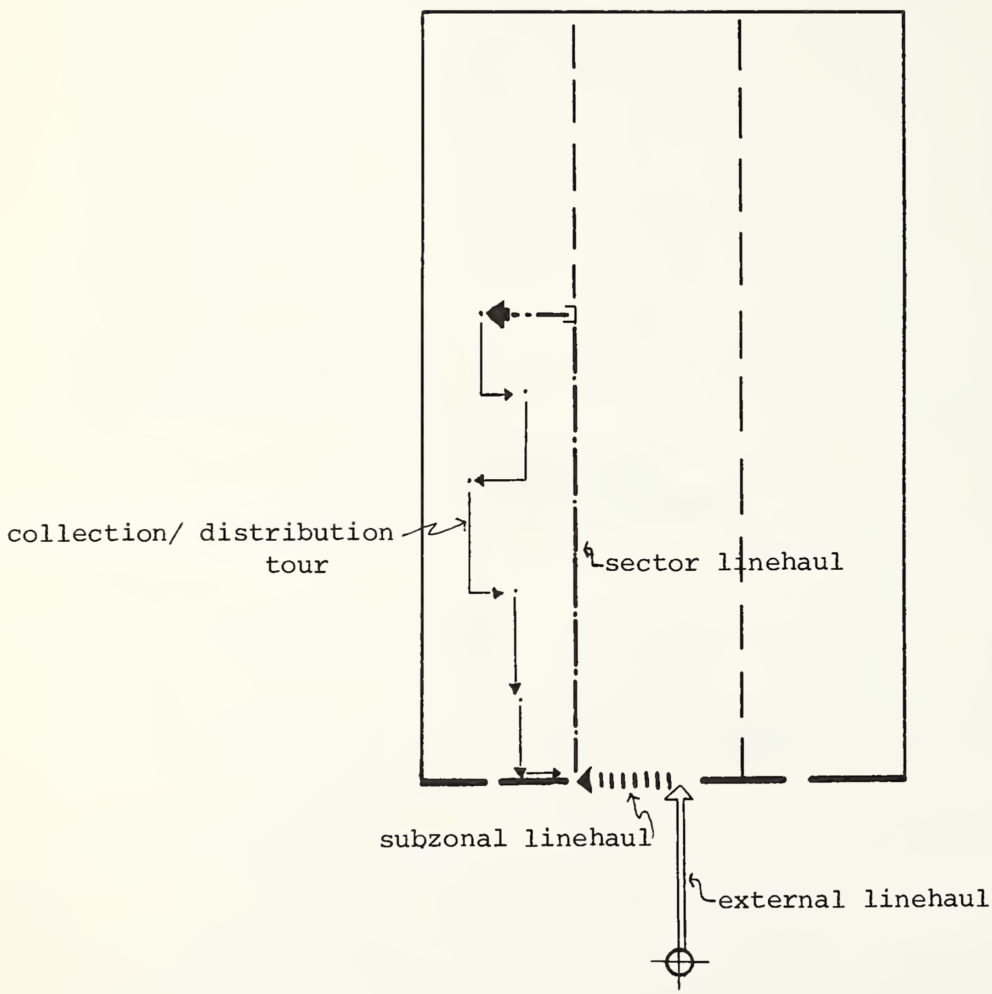


Figure A.6

Subscription Tour Components

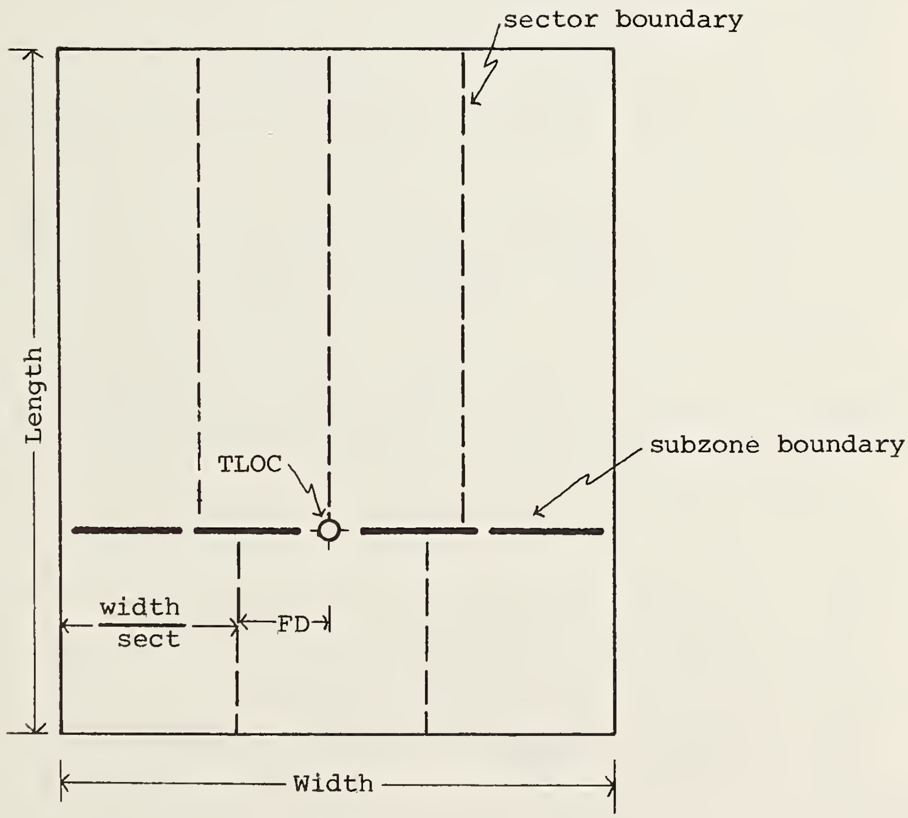


Figure A. 7

Variables Used in Subzonal Linehaul Distance Calculation

$$NLOC = INT\ [TLOC/(WIDTH/SECT)] + 1 \qquad [A-40]$$

where:

- NLOC = sector in which entry is located
- INT(.) = integer portion of (.)
- TLOC = location of entry
- WIDTH = width of subzone
- SECT = number of sectors in subzone

Next, the distance to the first sector to the right of the transfer point is calculated as:

$$FD = TLOC - (NLOC - 1) * (WIDTH/SECT)$$

Once these two terms are specified, the average subzonal linehaul distance is calculated as:

$$DL = [(NLOC - 2)(NLOC - 1) + \max(0, SECT - NLOC - 1)] (SECT - NLOC)(WIDTH/SECT)/(2\ SECT) + [FD\ (NLOC - 1) + (WIDTH/SECT - FD)(SECT - NLOC)]/SECT \qquad [A-41]$$

The sector linehaul distance (DSL) depends on the number of passengers the vehicle must pick up during its cycle and the length of the subzone. The number of stops for the vehicle is:

$$STOPS = DEM/VEH * CYCLE/60 \qquad [A-42]$$

where:

DEM = demands per hour

The sector linehaul is then computed as:

$$DSL = (LENGTH + WIDTH/SECT)(STOPS)/(STOPS + 1) \qquad [A-43]$$

where:

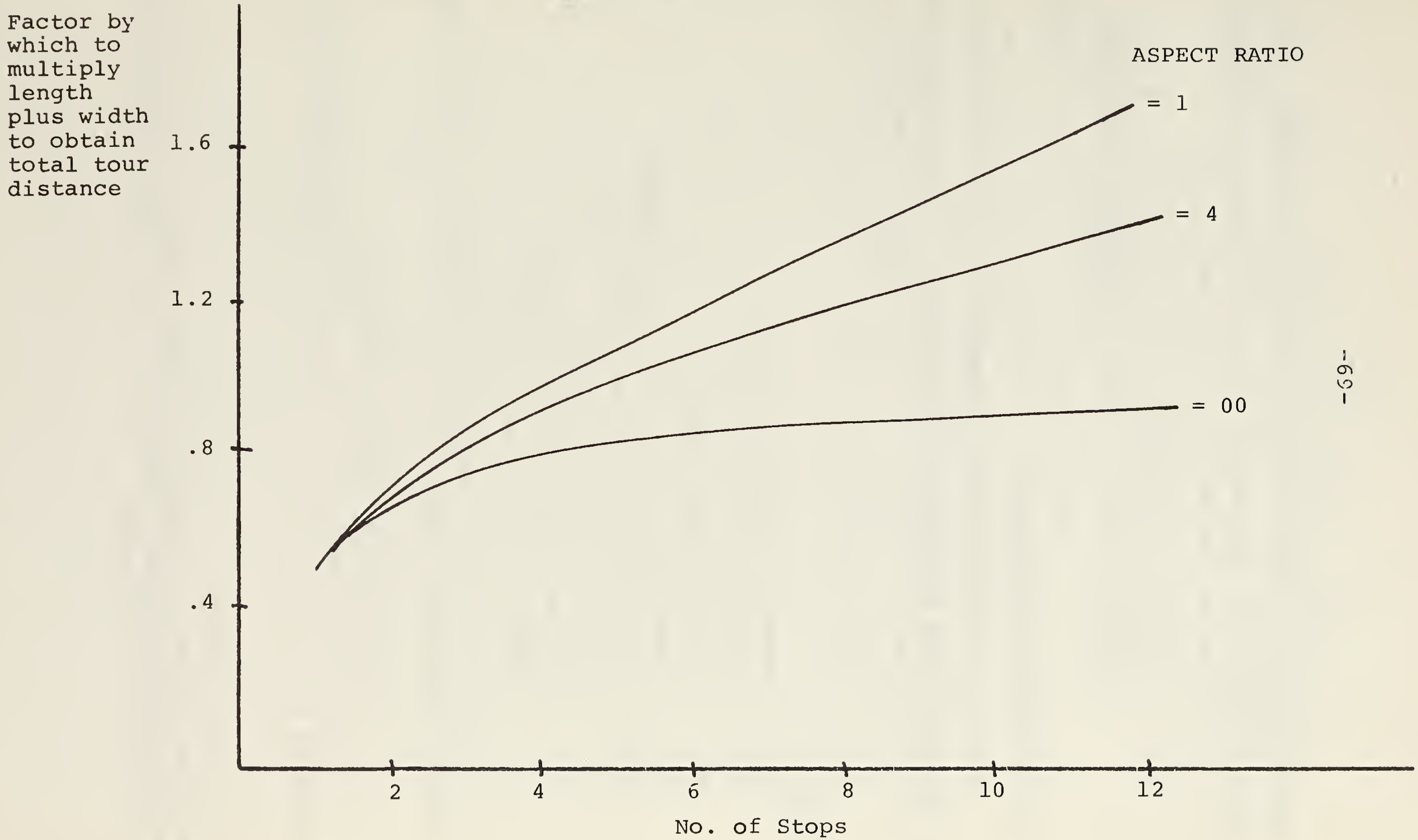
LENGTH = the length of the subzone (sector)

The final portion of the vehicle tour is the collection/distribution tour. Calculation of the collection/distribution distance (DCD) is based on the Mason-Mumford simulation of optimal vehicle tours connecting random points within a rectangular service area. The results of that analysis, presented in Figure A.8, (as the factor by which to multiply the length plus width of the area) indicate that the collection/distribution tour length is

Figure A.8

Collection/Distribution Tour Distance Factor
As a Function of Aspect Ratio and Number of Stops

(Mason-Mumford Results)



dependent on the number of stops and the aspect ratio (ratio of length to width) of the service area. The curves in Figure A.8 have been fitted to the following functional form:

$$DCD = (LENGTH + WIDTH/SECT)\left[(0.8 - 0.18/AR) + (0.01 + 0.084/\sqrt{AR})\ STOPS - \frac{(0.31 - 0.18/AR) + 0.084/\sqrt{AR}}{STOPS}\right] \qquad [A\text{-}44]$$

where AR is the aspect ratio

Given the distance of each element of the vehicle tour, it is possible to determine the feasibility of providing service in the specified cycle time. Total vehicle tour time is:

$$T = (2 * DLH + 2 * DL + DSL + DCD)/V + STOPS * PT + LO \qquad [A\text{-}45]$$

where:

DLH = external linehaul distance
DL = subzone linehaul distance
DSL = sector linehaul distance
DCD = distribution/collection tour distance
STOPS = pick-ups/drop-offs per vehicle tour
PT = time per pick-up/drop-off[1]
LO = layover time at transfer point
V = vehicle speed in miles/minute

If T is larger than CYCLE, service is infeasible. In such cases, a larger vehicle fleet should be input.

A.3.3 Calculation of Level of Service

For feasible systems, the level-of-service variables are calculated as:

---

[1]Note that different values for PT can be input for the collection and distribution tours, comparable to the "load, unload" variables of the many-to-many model.

$$RT = (DL + DLH)/V + (DCD/V + PT * STOPS) * (STOPS + 1)/(2 * STOPS) \quad [A-46]$$

$$SD = HDWY/2 \quad [A-47]$$

$$WT = LO/2 \quad [A-48]$$

where:

RT = average ride time for passengers in a subzone

SD = average schedule delay

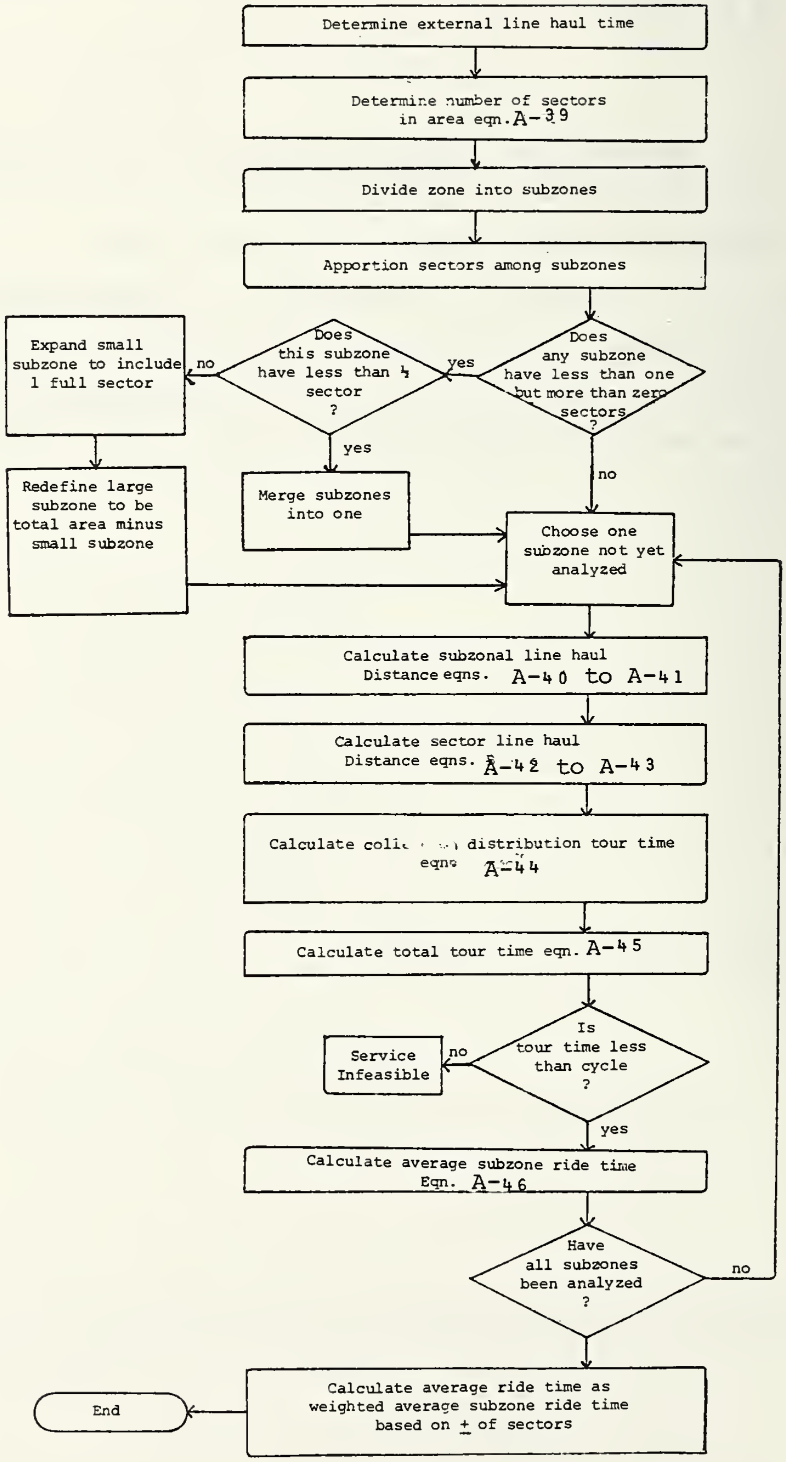
WT = average wait time at transfer point

Average ride time for all passengers is calculated by taking a weighted average of ride times based on subzone area.

The steps involved in running the subscription model are described sequentially in Figure A.9.

Figure A.9

Subscription Service Flow Chart



Appendix B

Detailed Model Results

Introduction

This appendix provides the user with a set of graphs which represent the results of a series of runs of all three models. The intention was to cover a wide range of typical situations, such that, in most cases, there will be no need to actually exercise the models themselves. Clearly, because of the large number of parameters contained in each model, it is likely that no real world application will match the modeled systems exactly. Nevertheless, by using realistic parameter settings and suitable default values it was felt that many real world situations can be reasonably approximated by the system designs considered. Straight-line interpolation is suggested for situations which fall between those considered in the graphs.

All of the graphs are set up such that wait and ride times are predicted as a function of the demand rate, for various vehicle fleet sizes. This format was felt to be the most convenient for persons using the models within the UTPS context. Values of transfer times and schedule delay, which are simple functions of layover time and cycle time or headway, are not included in the graphs, since they can easily be computed from input parameters.

Model results are grouped in a series of "plates", where each plate represents a given scenario. The "M" series of plates are for many-to-many systems, where different plates correspond to different area sizes. The "O" plates are for many one-to-one systems; different plates relate to different

area sizes and headway/cycle time combinations. The "S" series are for subscription service; different plates correspond to different service area sizes (with different headway/cycle time combinations included on a single plate). A single plate (C) compares the results for different systems in the same service area. Table B.1 lists all of the plate and figure numbers and important characteristics of the systems represented.

Input parameter values common to all (or most) runs were:

- α (manual dispatch adjustment factor) = .5 for all many-to-many runs.
- Vehicle fleet adjustment factor = .85 for all many-to-many runs.
- Average vehicle speed = .25 miles/minute.
- Load (pick-up) time = 1.0 minute; Unload (drop-off) time = .5 minute.
- Layover time = 10% of DRT headway for all many-to-one and subscription runs (except for 60 minute DRT headways where layover = 4.5 minutes).
- Street network adjustment factor = 1.271.
- Transfer point located at the corner of the service area.

Other important parameters are listed individually for each plate. See Appendix A for a full explanation of each variable.

In addition to the basic plates, a number of additional figures and tables are provided to indicate to the user how certain situations which are different from the base systems can be considered. Following the plates, a set of detailed examples are provided, illustrating how the plates (and adjustments) can be used to estimate access and egress time for DRT feeder systems.

Table B.1: List of Graphical Outputs

Plate	Figure Nos.	System	Important Parameters
M-1	B.1-1 - B.1-2	Many-to-Many	Area = 2
M-2	B.2-1 - B.2-2	Many-to-Many	Area = 4
M-3	B.3-1 - B.3-2	Many-to-Many	Area = 6
M-4	B.4-1 - B.4-2	Many-to-Many	Area = 8
M-5	B.5-1 - B.5-2	Many-to-Many	Area = 12
M-6	B.6-1 - B.6-2	Many-to-Many	Area = 16
M-7	B.7-1 - B.7-2	Many-to-Many	Area = 20
M-8	B.8-1 - B.8-2	Many-to-Many	Area = 4; Impact of Advanced Requests
M-9	B.9-1 - B.9-2	Many-to-Many	Area = 8; Impact of Advanced Requests
O-1	B.10-1 - B.10-3	Many-to-One	Area = 2; Cycle = 30, Headway = 10
O-2	B.11-1 - B.11-3	Many-to-One	Area = 2; Cycle = 30, Headway = 30
O-3	B.12-1 - B.12-3	Many-to-One	Area = 4; Cycle = 30, Headway = 10
O-4	B.13-1 - B.13-3	Many-to-One	Area = 4; Cycle = 30, Headway = 30
O-5	B.14-1 - B.14-3	Many-to-One	Area = 6; Cycle = 30, Headway = 10
O-6	B.15-1 - B.15-3	Many-to-One	Area = 6; Cycle = 30, Headway = 30
O-7	B.16-1 - B.16-3	Many-to-One	Area = 6; Cycle = 60, Headway = 30
O-8	B.17-1 - B.17-3	Many-to-One	Area = 8; Cycle = 30, Headway = 10
O-9	B.18-1 - B.18-3	Many-to-One	Area = 8; Cycle = 30, Headway = 30
O-10	B.19-1 - B.19-3	Many-to-One	Area = 8; Cycle = 60, Headway = 30
O-11	B.20-1 - B.20-3	Many-to-One	Area = 4; In/Out of Phase Tradeoff
O-12	B.21-1 - B.21-3	Many-to-One	Area = 4; Impact of Transfer Point Location
O-13	B.22-1 - B.22-3	Many-to-One	Area = 4; Impact of Direction of Demand
O-14	B.23-1 - B.24-3	Many-to-One	Area = 4; Impact of Many-to-Many Passengers
S-1	B.24-1 - B.24-3	Subscription	Area = 2
S-2	B.25-1 - B.25-3	Subscription	Area = 4
S-3	B.26-1 - B.26-3	Subscription	Area = 6
S-4	B.27-1 - B.27-3	Subscription	Area = 8
S-5	B.28-1	Subscription	Area = 12
S-6	B.29-1	Subscription	Area = 16
S-7	B.30-1	Subscription	Area = 18
C-1	B.31-1 - B.31-4	Combined	Area = 6, Vehicle = 8

B.1 Model Results (Nomographs)

The results of a series of model runs are presented in Figures B.1 - B.31. At the end of this section Table B.1 lists the contents of these figures.

The first set of plates represents many-to-many service. Predicted values shown are wait time for immediate request passengers (feeder and non-feeder) and ride time for feeder passengers. If it is assumed that transfers between the DRT and line haul vehicles are not coordinated, the transfer time for feeder to line haul passengers can be computed as one-half the line haul headway. For line haul to distribution passengers, the transfer time is equal to the wait time for immediate request passengers, if the request for distribution service is assumed to be made at the time of alighting from the line haul vehicle. If a more effective system of advance requests is employed[1] (i.e., requests are made prior to boarding or on board the line haul vehicle), the transfer time can be considered to be very small, and arbitrarily set to about 2-3 minutes (in all cases).

---

[1]These are not true advance requests, since they would be made within 30 minutes of actual trip time, rather than one or more hours in advance. Note that the model does not predict wait time for advance request passengers, although the impact of such requests on other passengers is considered. In the ideal system, advance requests would result in effectively no wait time (as is the case for subscription service). In reality, there will always be a few minutes wait time associated for advanced request passengers, where wait time is the difference between actual and promised pick up time. It is suggested that the user wishing to consider advance request passengers use an arbitrary, fixed wait time of 2-4 minutes.

The transfer points for all systems analyzed were located at the corner of the service area. Ride time for many-to-many passengers is a linear function of ride time for feeder passengers, and can be computed as $RT(i) = \frac{DD(i)}{DD(f)} RT(f)$ (i.e., the ratio of average many-to-many trip distance to average feeder trip distance times the mean feeder ride time). The computation of mean trip distance is discussed in Appendix A. An example presented in Section B.2 illustrates how a transfer point located in the center of the service area can be modeled.

All many-to-many results are for a manually dispatched system. As described in Appendix A, wait time in a computer dispatch system is assumed to be a linear function of wait time in a manual system, while ride time is assumed to be the same in both.

Note that wait time for the many-to-many passenger increases much more rapidly than ride time (and, in fact, ride time in certain cases appears to be leveling off). This results from the use of a wait time/ride time tradeoff factor (β) described in Appendix A. This factor is intended to represent a realistic dispatching strategy, wherein new passengers will not be assigned to a vehicle once it starts becoming crowded, until other passengers are dropped off. This results in a steady state vehicle occupancy, and hence a virtually constant ride time, while wait time will increase rapidly with demand.

Most of the figures presented are for systems which have no advanced requests. The impacts of advanced requests are shown in Figures B.8 and B.9. A series of model runs were made to develop a set of adjustment factors, presented in Table B.2. These factors would be used in the following manner:

$$WT_a = WT + F_w(WT + RT)$$

$$RT_a = RT + F_r(WT + RT)$$

Table B.2. Factors for Adjusting WT and RT as a Function of the Percent Advanced Requests and Productivity

Productivity	2		4		6		8		10	
Pct. Advanced Request	WT Adj. (F_w)	RT Adj. (F_r)	WT Adj. (F_w)	RT Adj. (F_r)	WT Adj. (F_w)	RT Adj. (F_r)	WT Adj. (F_w)	RT Adj. (F_r)	WT Adj. (F_w)	RT Adj. (F_r)
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	0.00	0.00	0.03	0.02	0.06	0.03	0.09	0.05	0.13	0.06
20%	0.01	0.00	0.05	0.03	0.11	0.06	0.17	0.09	0.22	0.12
30%	0.01	0.01	0.08	0.04	0.16	0.09	0.24	0.13	0.31	0.17
40%	0.02	0.01	0.10	0.05	0.21	0.11	0.31	0.17	0.40	0.22
50%	0.02	0.01	0.12	0.06	0.25	0.14	0.38	0.20	0.49	0.26
60%	0.02	0.01	0.14	0.08	0.30	0.16	0.45	0.24	0.57	0.31
70%	0.03	0.01	0.16	0.09	0.34	0.18	0.51	0.27	0.66	0.35
80%	0.03	0.02	0.18	0.10	0.38	0.21	0.57	0.31	0.74	0.40

where:

WT_a/RT_a = adjusted wait and ride time

WT/RT = unadjusted wait and ride time

F_w/F_r = factor for wait time and ride time

The many-to-many service area considered ranged from 2-20 mi^2 in size; this was felt to be the range within which 95% of all many-to-many DRT systems would fall.

The many-to-one runs cover a variety of areas and vehicle fleet sizes, and feeder headway/line haul headway/cycle time combinations. Areas of up to 8 mi^2 only are considered, since it was felt to be highly unlikely that a cycled service would be implemented in a larger area (without being divided into smaller subareas). All systems in which the feeder headway (i.e., the time between successive feeder vehicle stops at the transfer point) and cycle time (i.e., the time spent by a single feeder vehicle between stops at the transfer point) are equal are examples of in-phase operation; cases in which they are not equal are examples of out-of-phase operation.

Note that, based on the above definition, the headway of the line haul vehicle is not important, and thus each graph may represent any line haul headway. If the line haul headway is set equal to the feeder headway, then feeder vehicles will be meeting every line haul vehicle. If the feeder headway is greater than the line haul headway, not every line haul vehicle will be met by a feeder vehicle. The importance of the line haul headway lies in measuring outbound transfer time. If the line haul and feeder headways are equal, the outbound transfer time is simply equal to one-half the scheduled layover time. If the line haul and feeder headways are not equal, the mean transfer time would equal one-half of the difference between the line haul and feeder headways, if it were assumed that a passenger would take any line haul vehicle. If it were

assumed that the passenger information system were sufficiently developed such that a passenger would take only the line haul vehicle which meets a feeder vehicle, transfer time would equal one-half the layover time; in this case, however, one-half the difference between headways could be interpreted as schedule delay. Note that, in all cases, inbound transfer time should be computed as one-half the layover time. Some of the tradeoffs between in-phase and out-of-phase operation are provided in Plate O-11.

Note that, unlike the case for many-to-many service where service times can be extrapolated beyond the ranges shown, the range of values shown for a given vehicle fleet in many-to-one service is the <u>full</u> range. Demand rates beyond that shown would result in an infeasible system (i.e., the vehicles would not be able to serve that many demands in the allotted cycle time). The same is true for the subscription service graphs.

Also note that in some of the many-to-one graphs, inbound ride time begins to <u>decrease</u> with increasing demand rate. This is caused by the fact that outbound demands are served first; beyond a certain point, the amount of time remaining to serve inbound requests decreases, resulting in fewer inbound demands served, reduced inbound ride times, and increased inbound wait times.

The base runs were made for situations in which the inbound and outbound demand rates are equal. Figures B.21-1 to B.21-3 illustrate the impact of an imbalance between inbound and outbound demand rates. A simple relationship between the percent of trips in a given direction and wait and ride time cannot readily be derived. However, an attempt has been made to develop an approximation to this relationship through a heuristic, described briefly below and illustrated in Example 4 (Section B.2). This procedure has not been extensively

tested, and is offered only to extend the usefulness of the nomographs. The user is urged to exercise the full model in cases of imbalanced demand, if at all possible.

To account for directionality of demand, a separate inbound and outbound demand level must be developed. The following equations indicate the steps required to make this calculation.

$$D_I = 2D\left(\frac{\%\ \text{Inbound}}{100}\right) = \text{Inbound Demand Level}$$

$$D_O = 2D\left(\frac{\%\ \text{Outbound}}{100}\right) = \text{Outbound Demand Level}$$

A further adjustment must be made in the overall demand level (D) if it is greater than the demand at which the knee of the inbound wait time graph begins (i.e., the point at which wait time begins to increase rapidly). If this is the case, the following adjustment is made:

$$D' = D_{KNEE} + (D - D_{KNEE})(\text{FACTOR})$$

where:

$$\text{FACTOR} = 2^{(1-.02(\%\ \text{Inbound}))}$$

Once these demand levels have been determined, level of service can be read directly from the nomographs using overall demand (D') for wait time inbound, inbound demand (D_I) for ride time inbound and outbound demand (D_O) for ride time outbound. If outbound or overall demand level exceeds the maximum feasible level (for a given vehicle fleet) presented in the monographs, the demand cannot be served. If inbound demand exceeds that presented in the ride time inbound nomograph, the ride time curve can be extrapolated, noting that the maximum ride time (which cannot be exceeded) is approximately equal to one-half the cycle time minus the layover time.

The base many-to-one cycled service graphs also depict situations in which all demands are for service to or from the

transfer point. Figures B.22-1 to B.22-3 illustrate the impact of many-to-many demands on overall service level. Many-to-many demands can be accounted for quite simply in calculating the service times of feeder passengers. The impact of many-to-many demands is to effectively increase the demand level, by increasing the overall number of stops (since many-to-many demands require two stops at locations other than the transfer point). Given that P% of the total of D demands are many-to-many demands, the service levels of feeder passengers can be determined by considering the service times at an effective demand rate $D' = (1 + P/100)D$. This methodology is illustrated in the context of Example 4.

The final adjustments to the nomograph results that are illustrated by an example relate to the location of the transfer points. As noted earlier, the base model runs used to create these plates assumed a transfer point at the edge of the service area. Plate 0-20 illustrates the difference between this case and a case where the transfer point is located at the center of the service area. Another possibility is for the transfer point to be located external to the service.

Again, a heuristic has been developed for adjusting the nomograph results for situations which differ from the base case. This adjustment is based on artificially adding or subtracting demands from the actual demand rate; the number to be added (subtracted) equals the amount of demands which could be served in the added (shorter) time it takes to get from a random point in the zone to the transfer point (i.e., this time is the difference between the time it takes to get to the <u>actual</u> transfer point, and the time it would have taken to get to a boundary transfer point. In the latter case, the distance traveled = $.638\sqrt{\text{area}}$).

This number of demands is calculated based on an assumption that the vehicles are operating fairly close to capacity.

Analysis has indicated that, in the general case, this occurs at a productivity level in the neighborhood of 9 demands per vehicle per hour; however, the number is more accurately determined by finding the point at which a passenger queue begins to form for inbound service. This is the point at which wait time begins to increase rapidly, i.e. the "knee" in the wait time curve. The following equations can be used to adjust the demand level.

$$D' = D + (\Delta T/\text{Cycle Time})(D_{KNEE})$$

$$\Delta T = (\text{avg distance} - \sqrt{.638 \quad \text{Area}})/15 \text{ mph}$$

where:

D_{KNEE} = demand level at the knee of the wait time curve

The difference in line haul time (one-way) must be added (or subtracted if negative) to the ride times once they have been read from the nomographs. This procedure is illustrated in Example 4 for the situation in which the transfer point is located beyond the service area.

Finally, consider that the 15 miles per hour speed used to develop all nomographs may not be appropriate in some areas, and it may be necessary to adjust the nomograph results to account for vehicle speed. The adjustment for the many-to-many model is quite simple, requiring both wait and ride times to be multiplied by the ratio of the vehicle speed used in the nomographs (15 mph) to the speed in the setting being analyzed. These adjustments are indicated by the equations below.

$$\text{Adjusted wait time} = \text{wait time} \times \frac{15 \text{ mph}}{\text{actual base speed}}$$

$$\text{Adjusted ride time} = \text{ride time} \times \frac{15 \text{ mph}}{\text{actual base speed}}$$

Many-to-Many Service
Area = 2 sq. mi.
(β = 0.1)

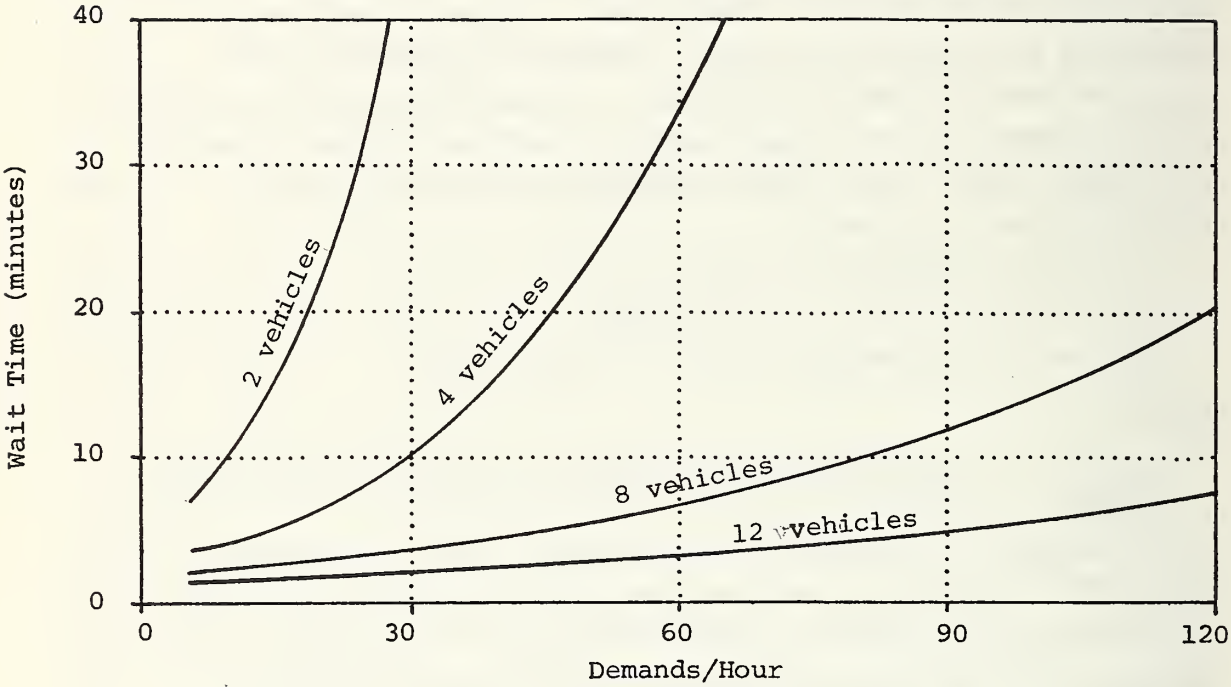


Figure B.1-1

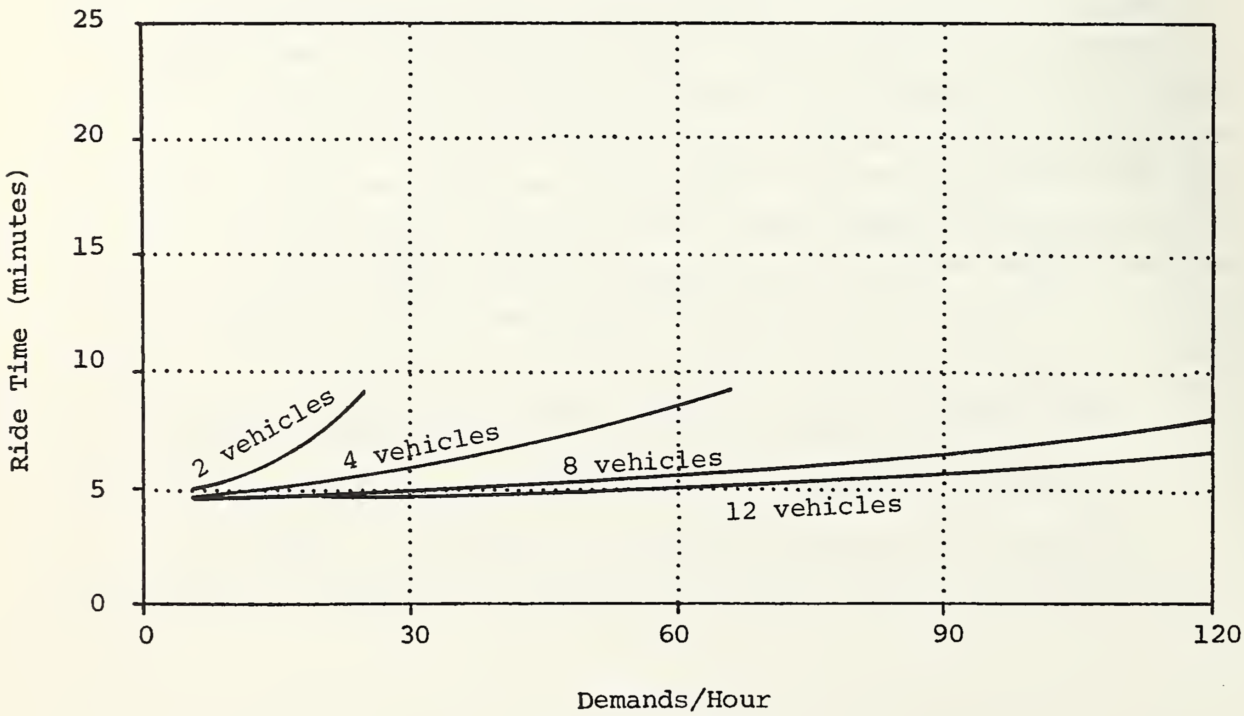


Figure B.1-2

Many-to-Many Service
Area = 4
(β = 0.2)

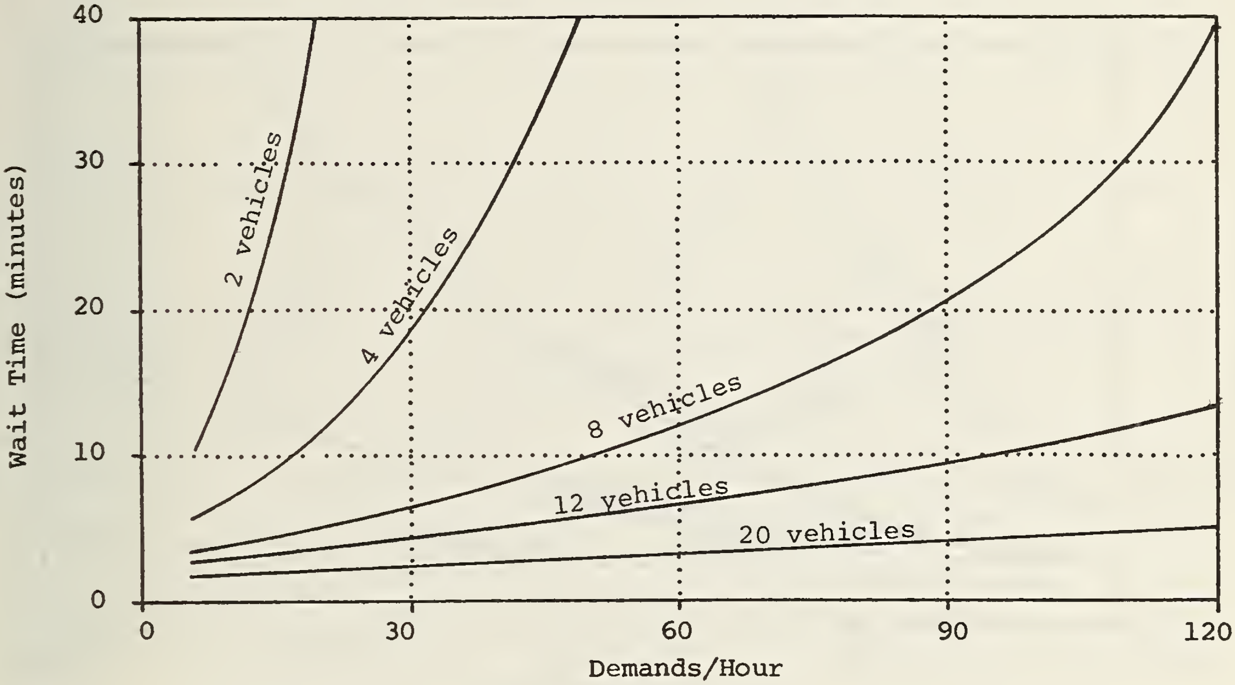


Figure B.2-1

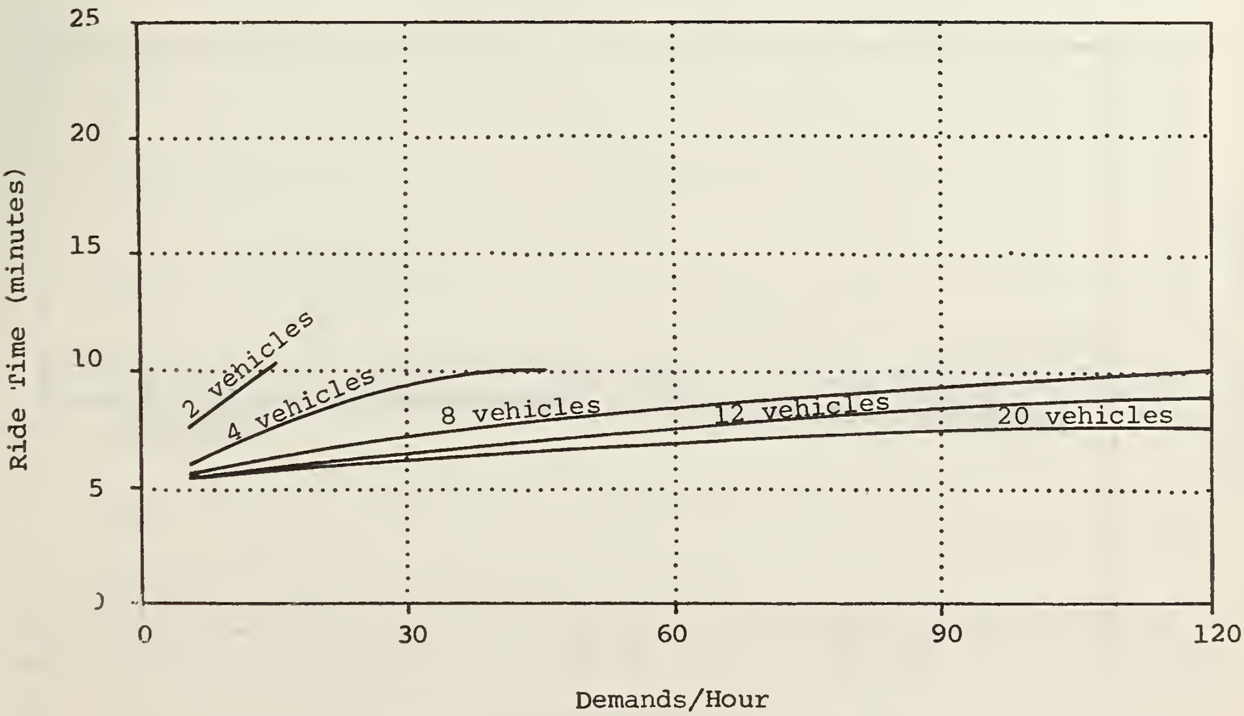


Figure B.2-2

Many-to-Many Service
Area = 6 sq. mi.
(β = 0.3)

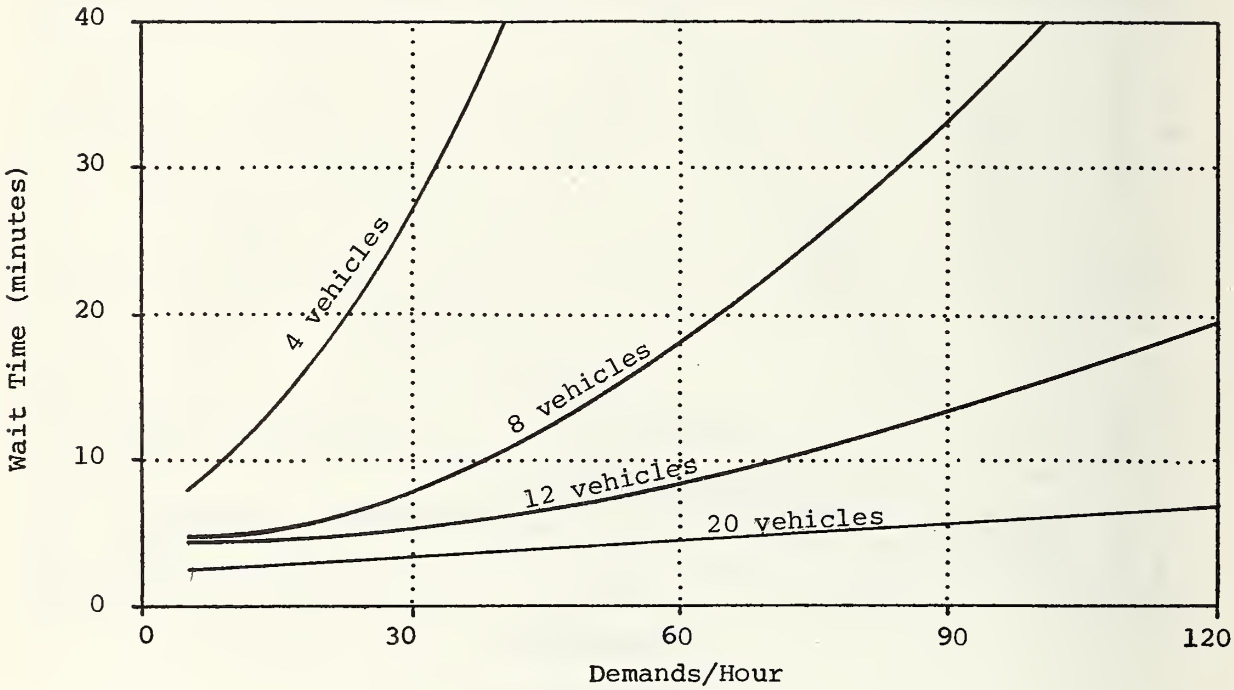


Figure B.3-1

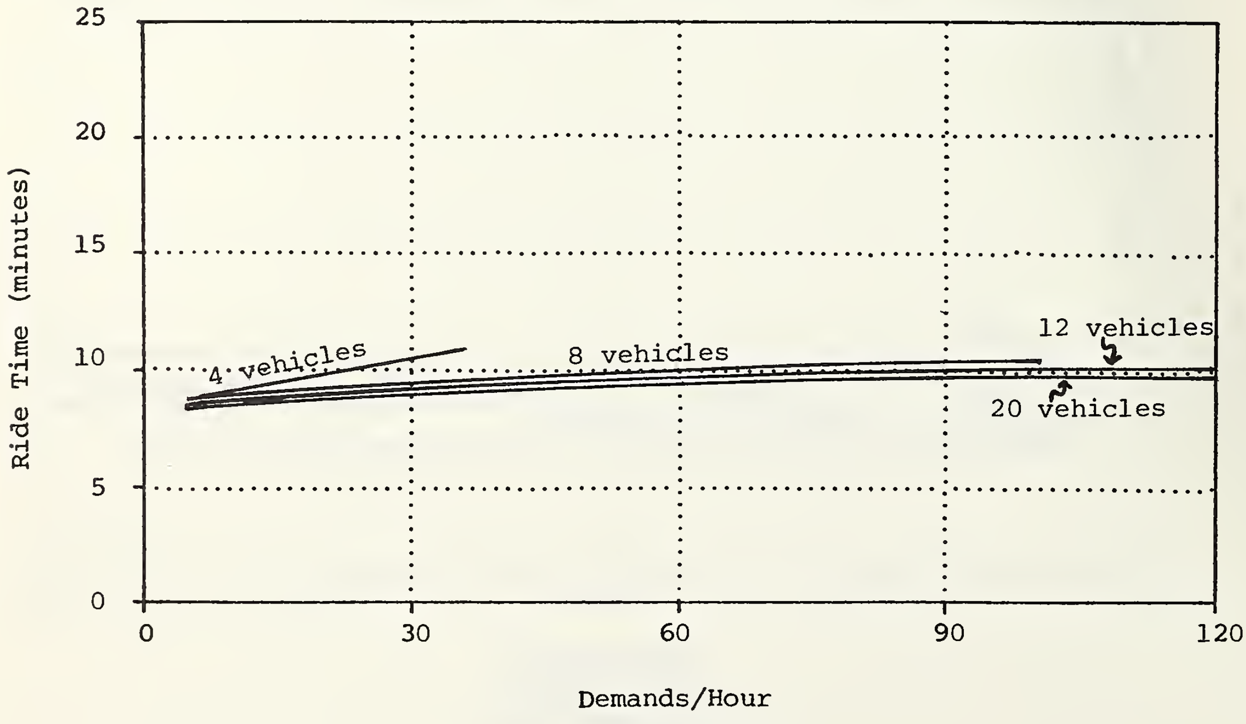


Figure B.3-2

Many-to-Many Service

Area = 8 sq. mi.

(β = 0.4)

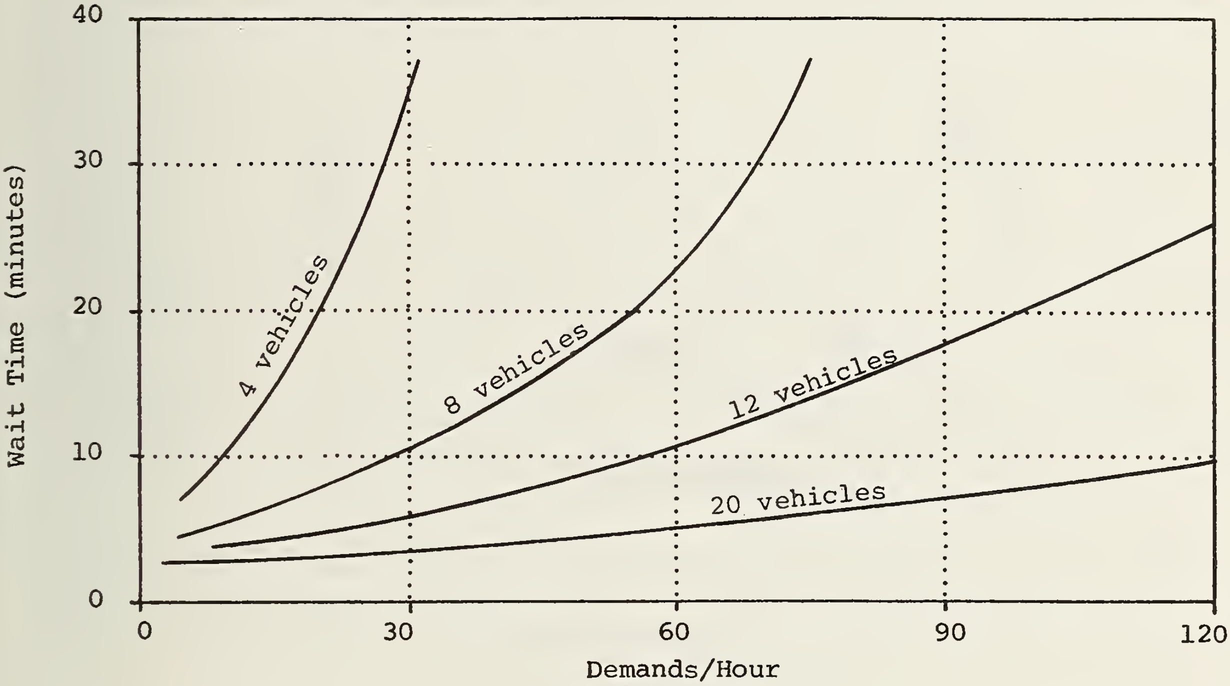


Figure B.4-1

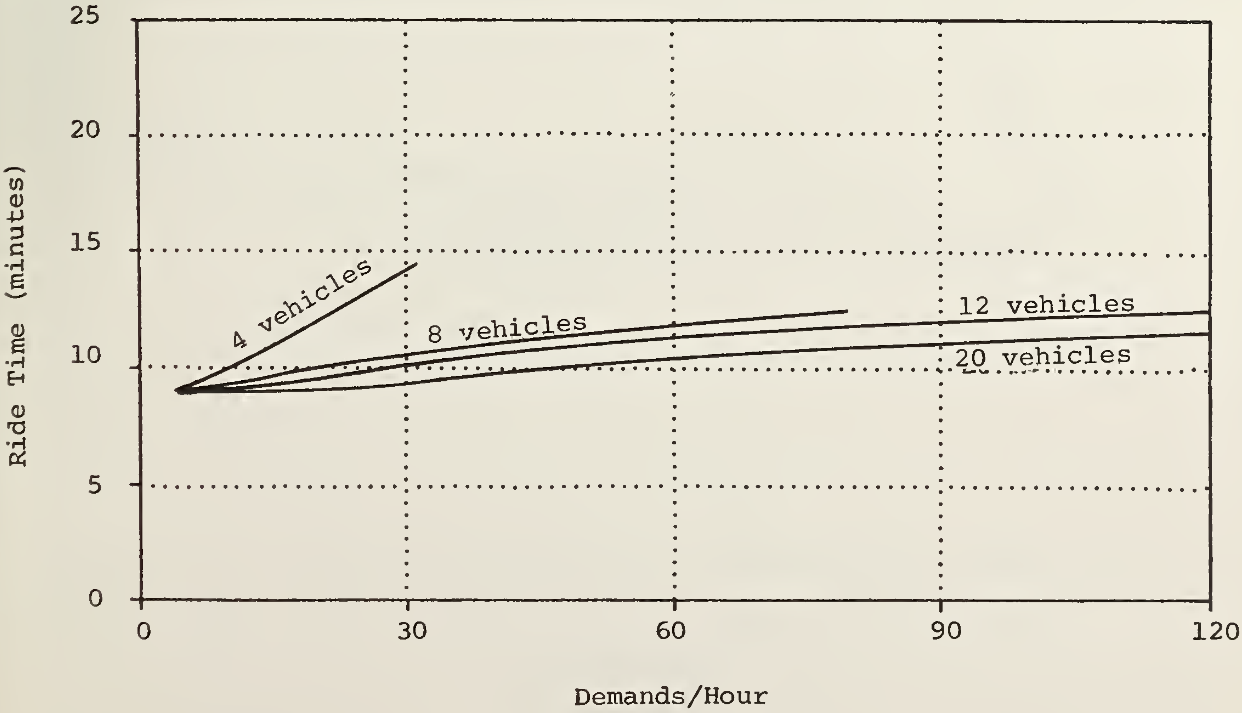


Figure B.4-2

Many-to-Many Service
Area = 12 sq. mi.
(β = 0.4)

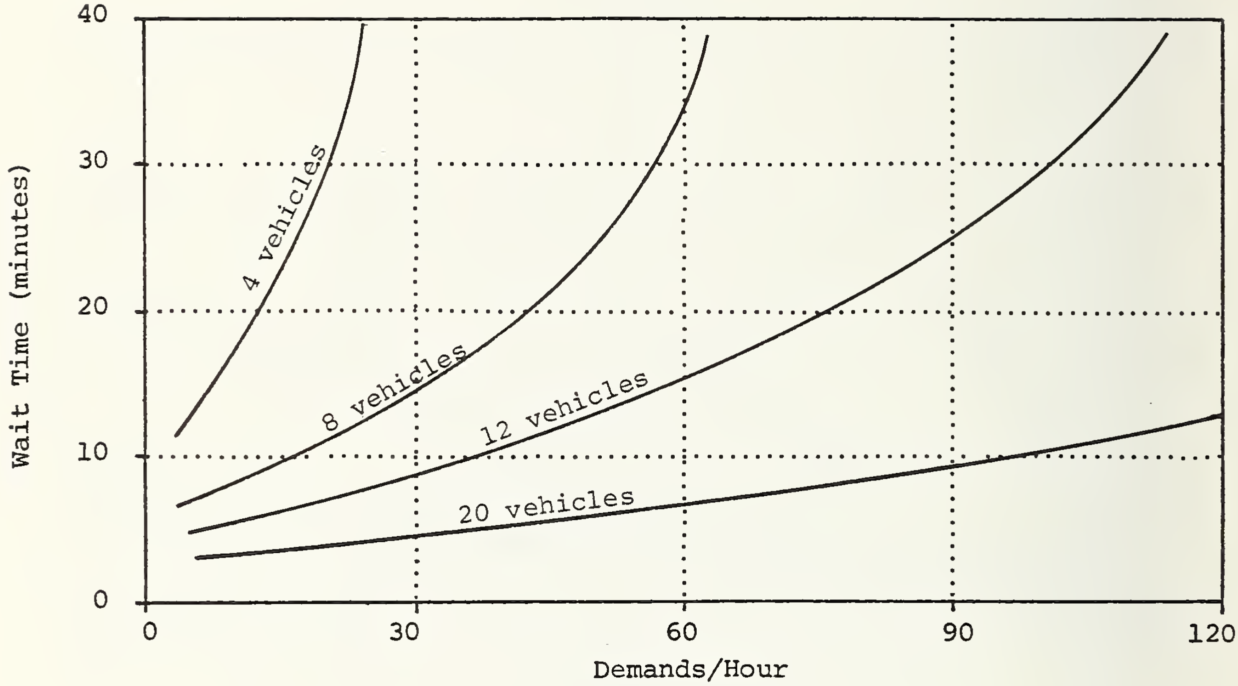


Figure B.5-1

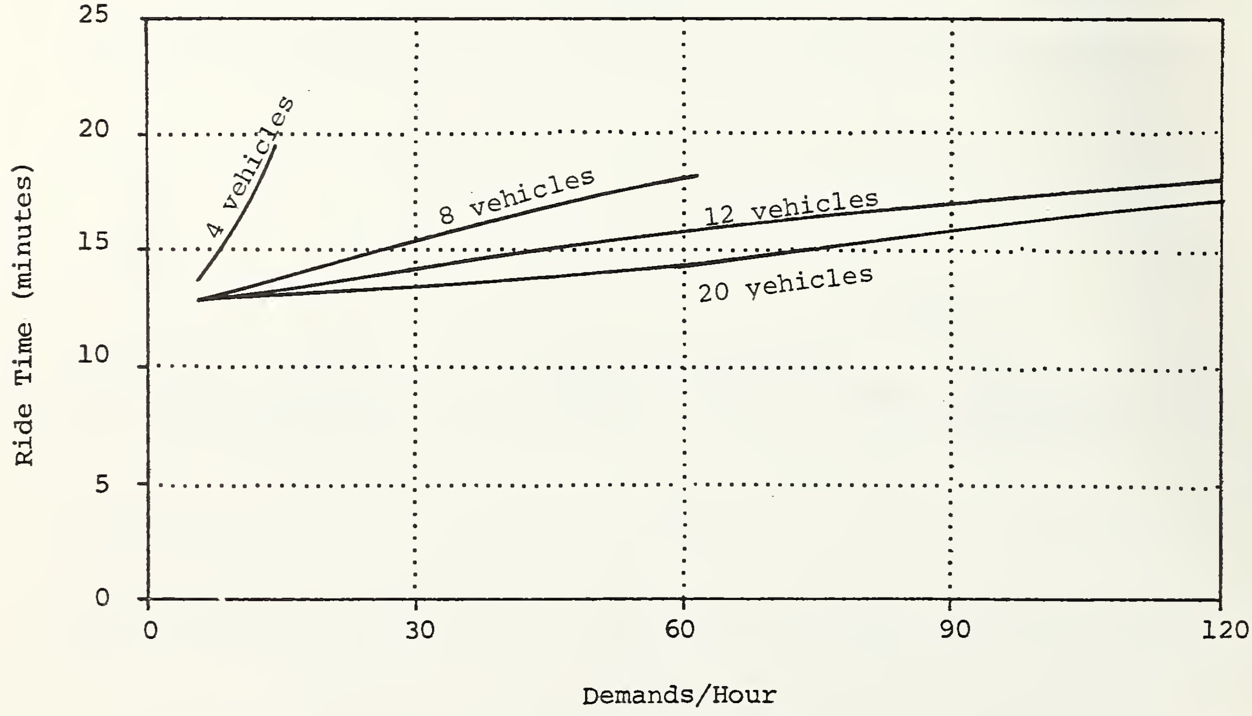


Figure B.5-2

Many-to-Many Service
Area = 16 sq. mi.
(β = 0.4)

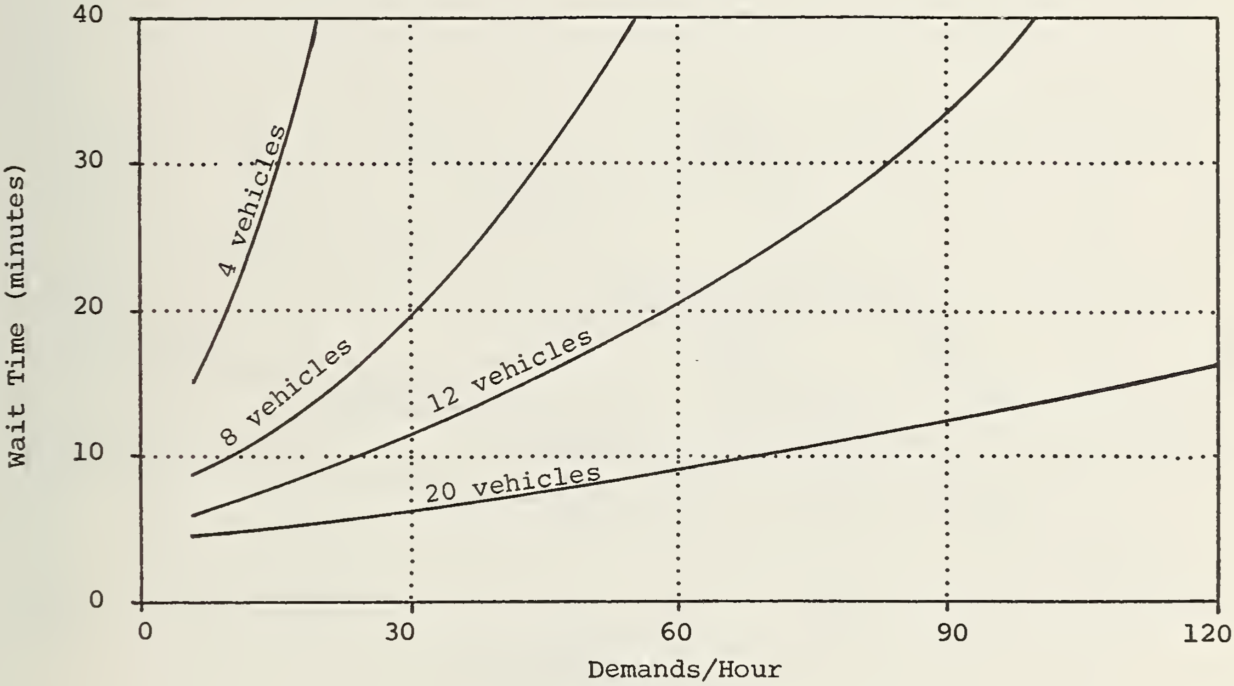


Figure B.6-1

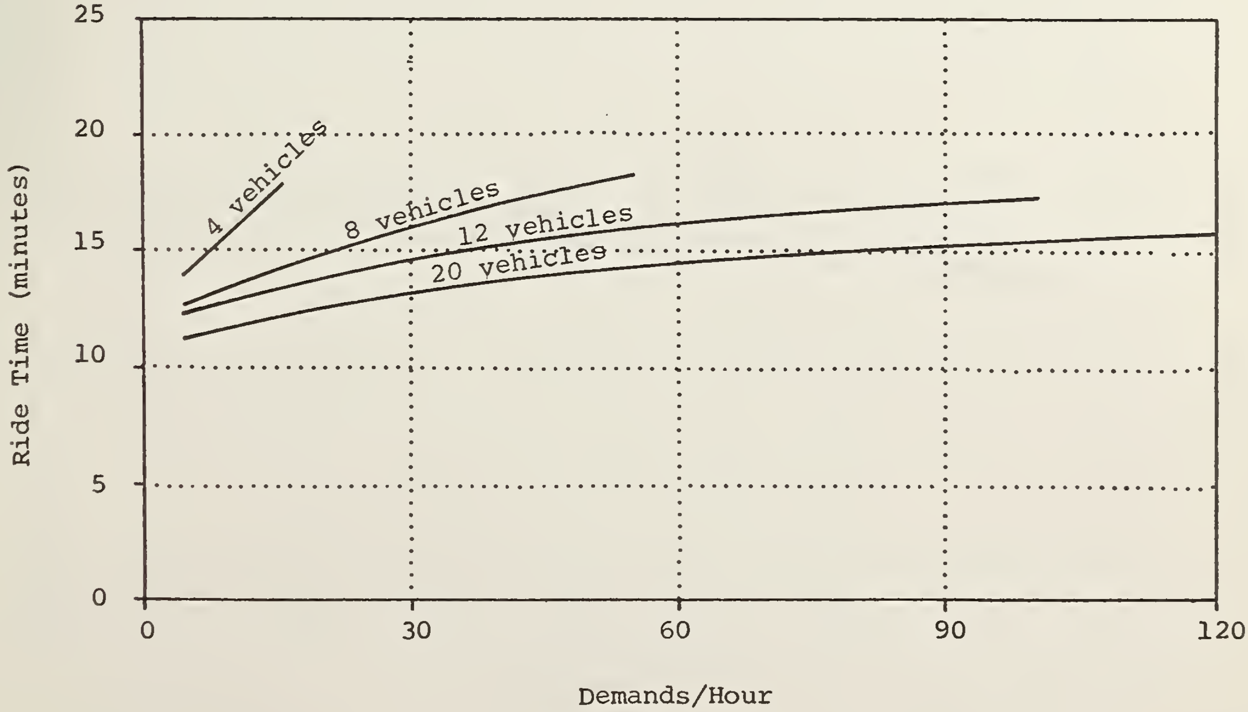


Figure B.6-2

Many-to-Many Service
Area = 20 sq. mi.
(β = 0.5)

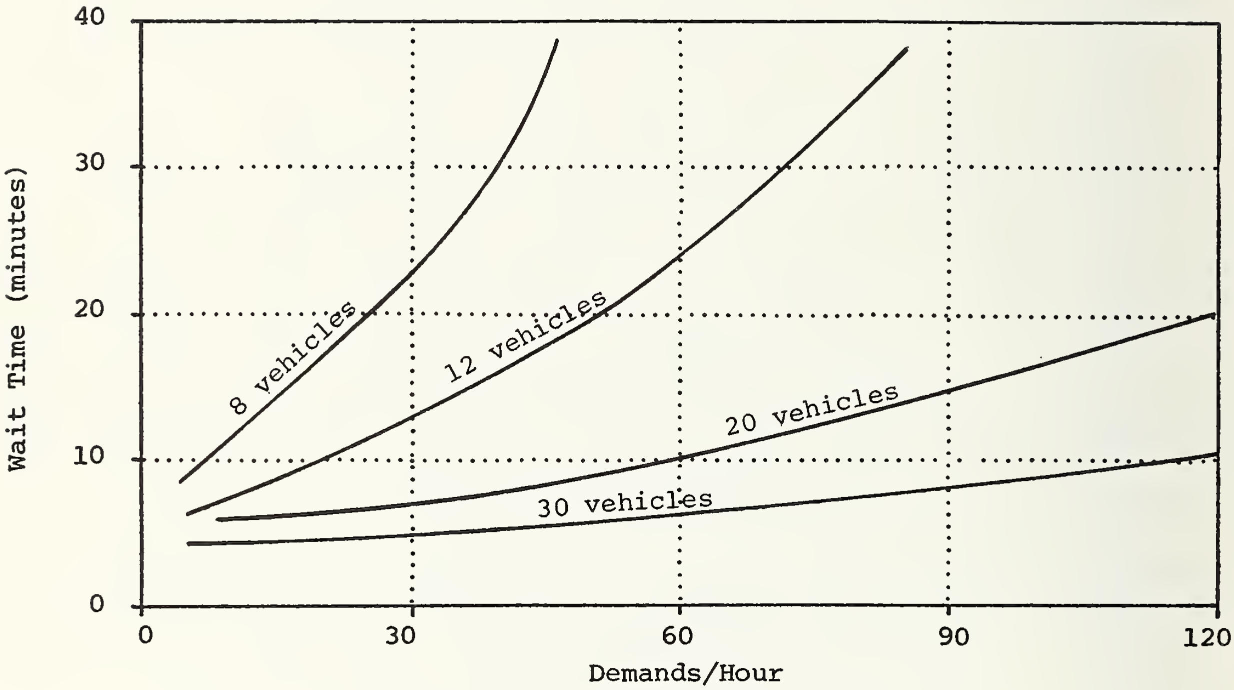


Figure B.7-1

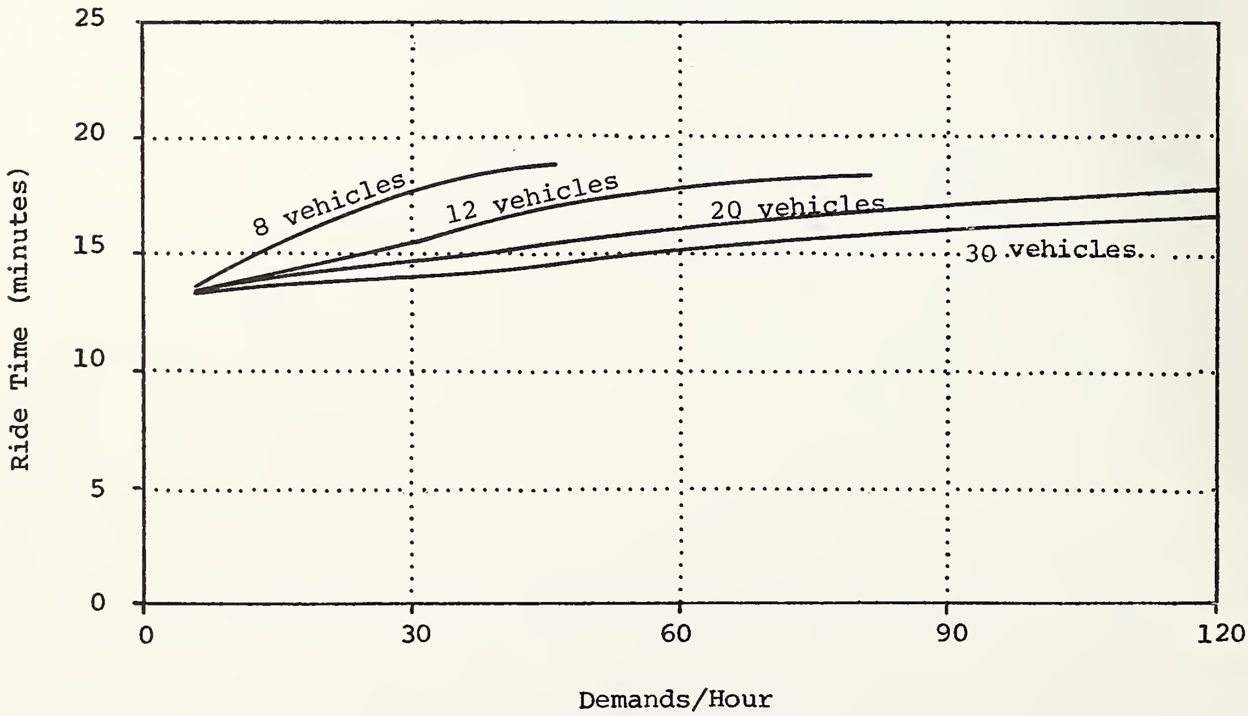


Figure B.7-2

Impact of Advanced Requests on Many-to-Many Service
Area = 4 sq. mi., 4 vehicles
(β = 0.2)

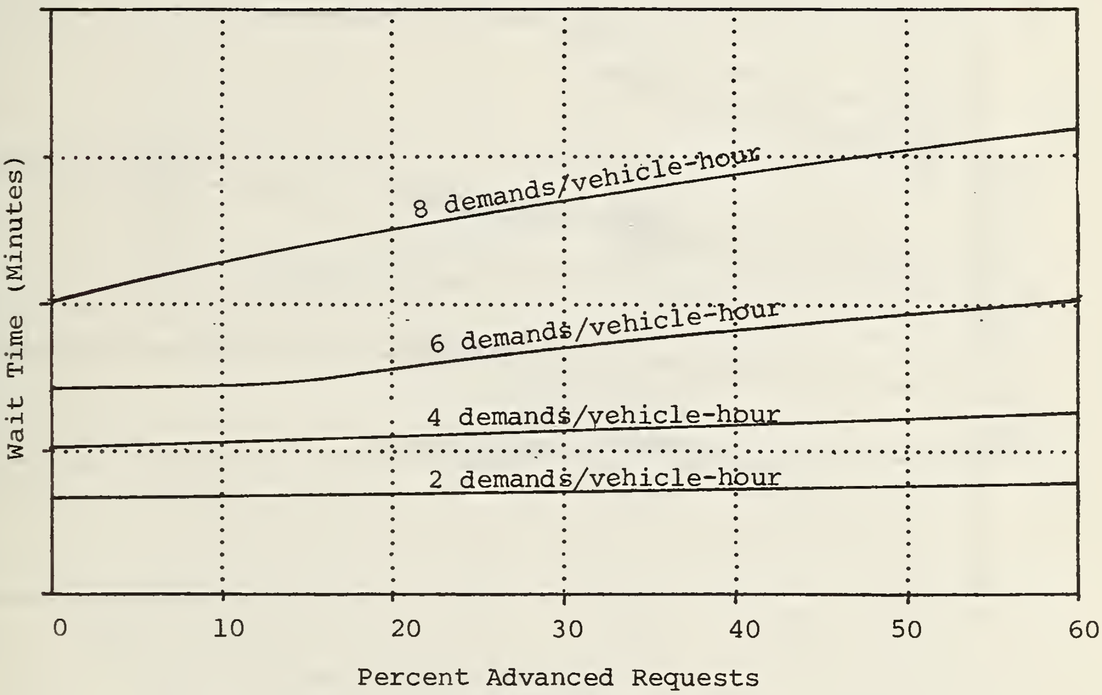


Figure B.8-1

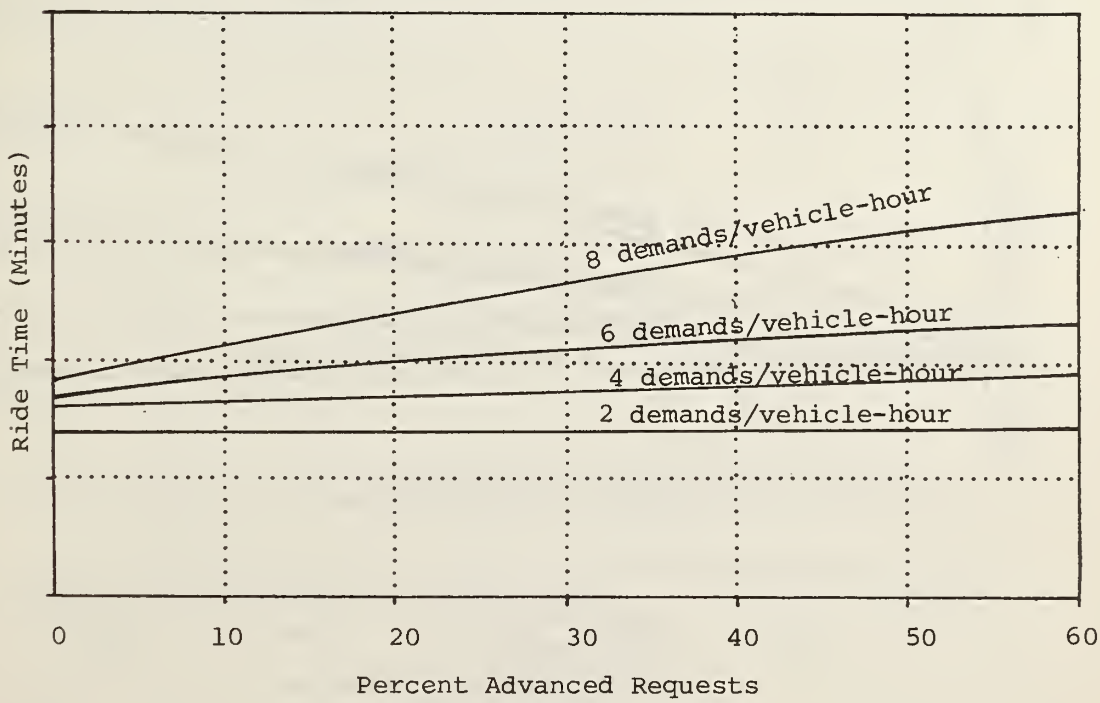


Figure B.8-2

Impact of Advanced Requests on Many-to-Many Service

Area = 8 sq. mi., 8 vehicles

(β = 0.4)

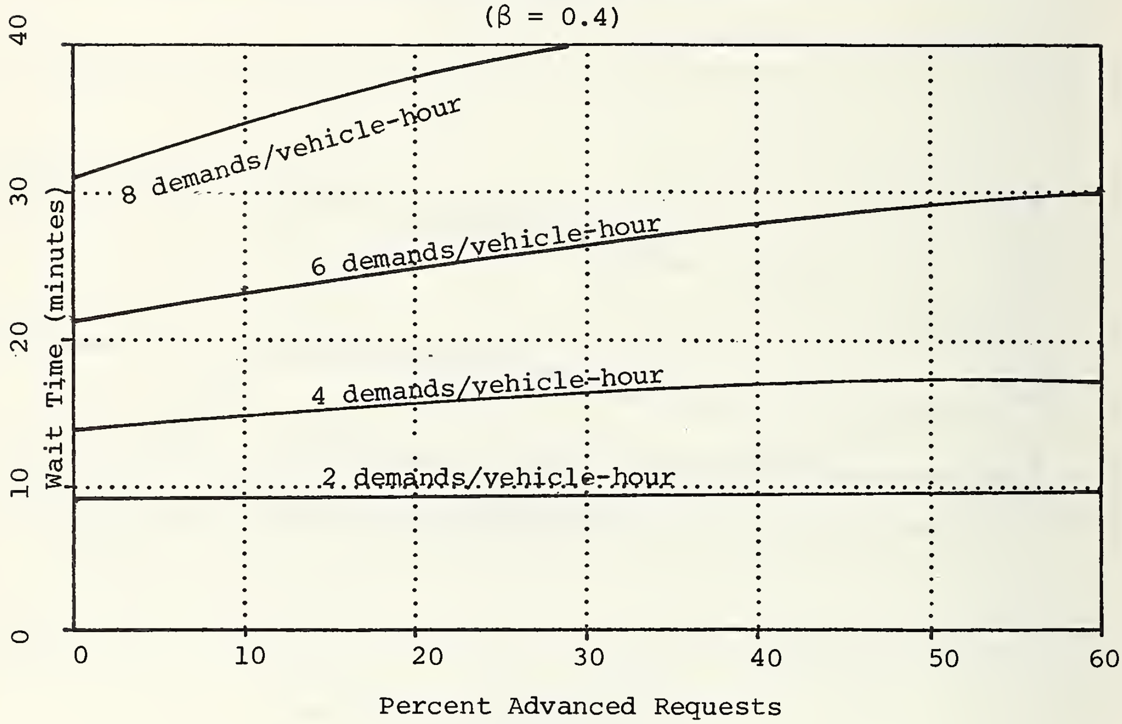


Figure B.9-1

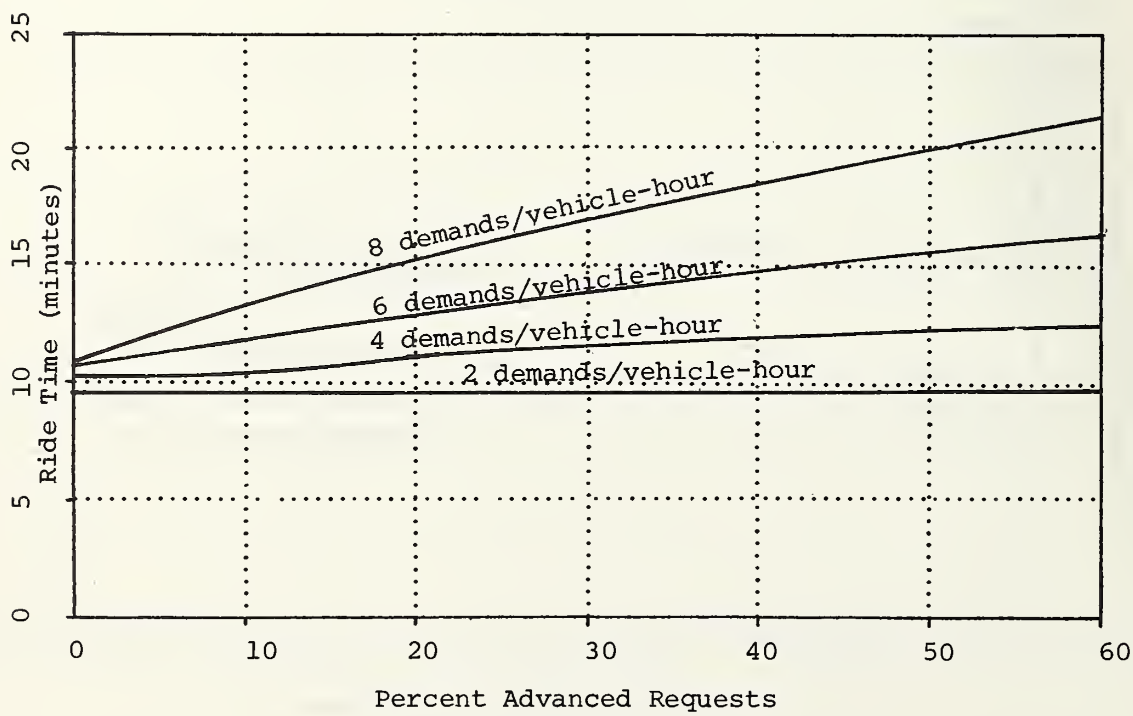


Figure B.9-2

Many-to-One Cycled Service
Area = 2 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 10 minutes

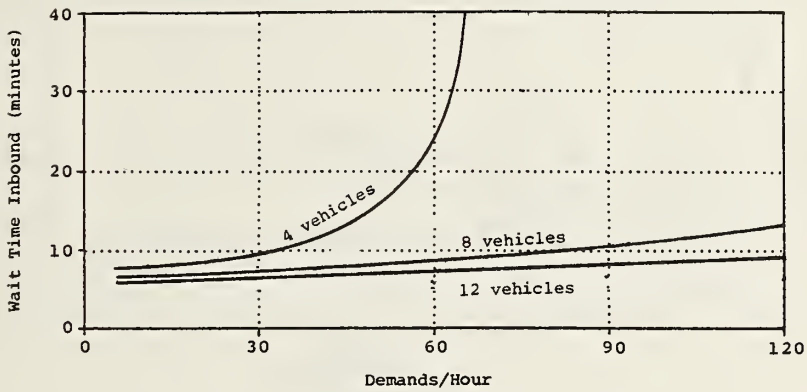


Figure B.10-1

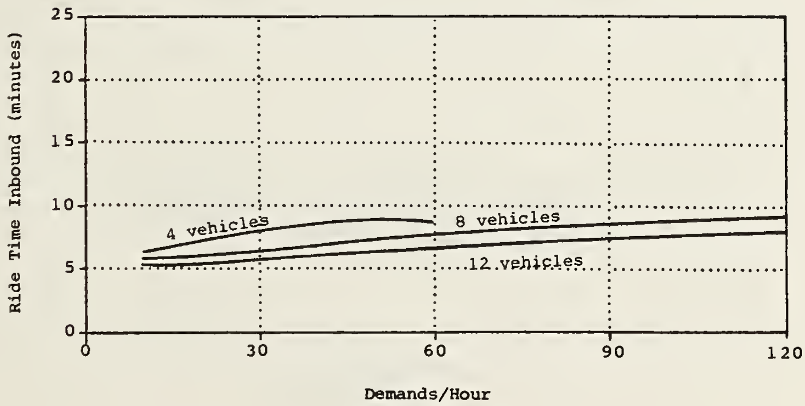


Figure B.10-2

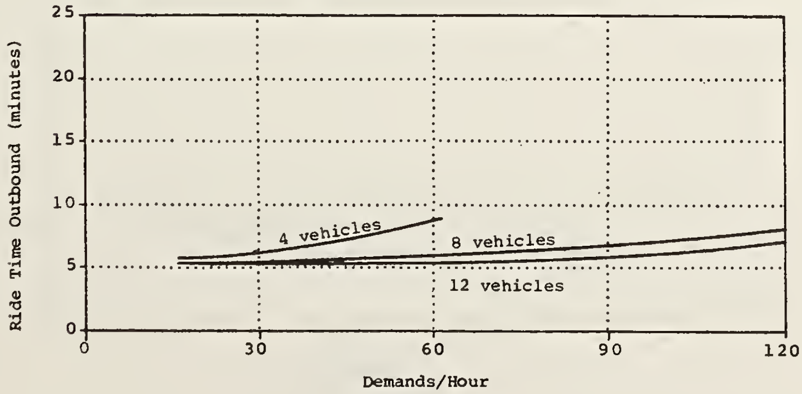


Figure B.10-3

Many-to-One Cycled Service
Area = 2 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 30 minutes

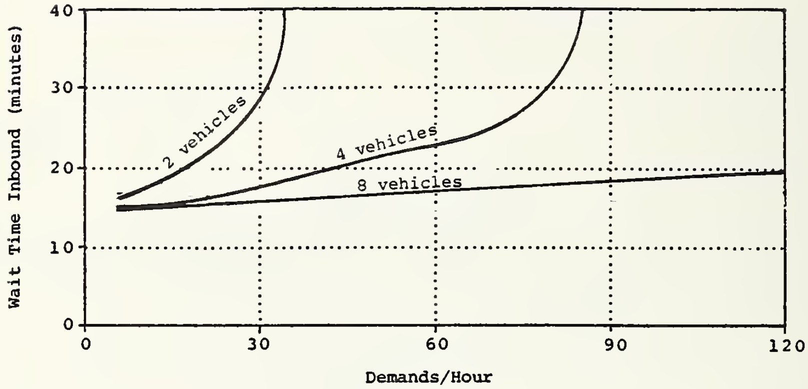


Figure B.11-1

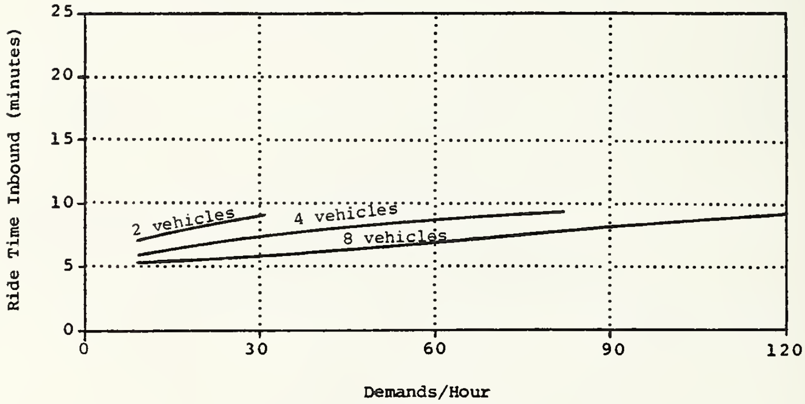


Figure B.11-2

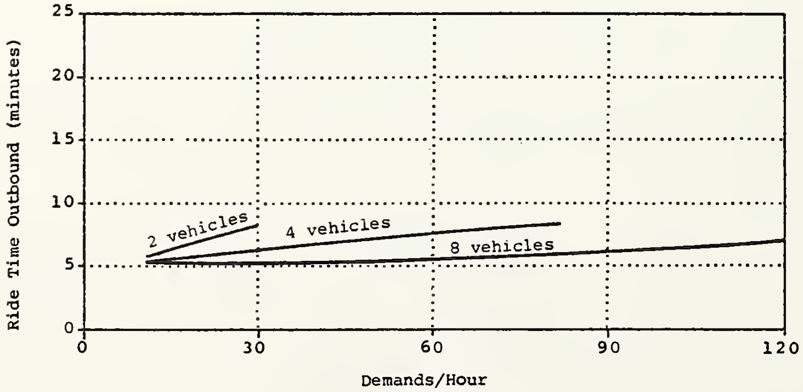


Figure B.11-3

Many-to-One Cycled Service
Area = 4 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 10 minutes

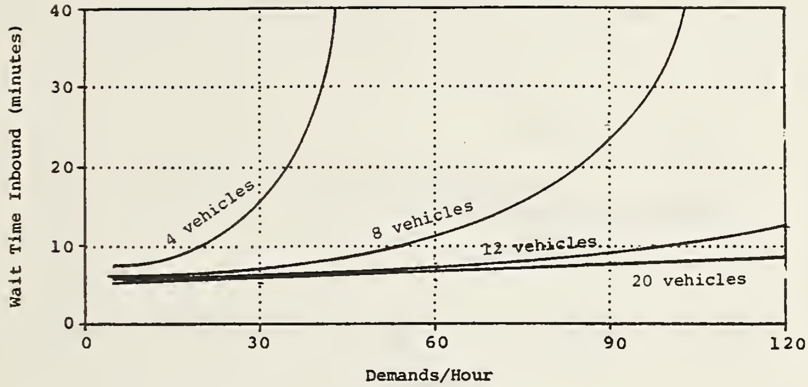


Figure B.12-1

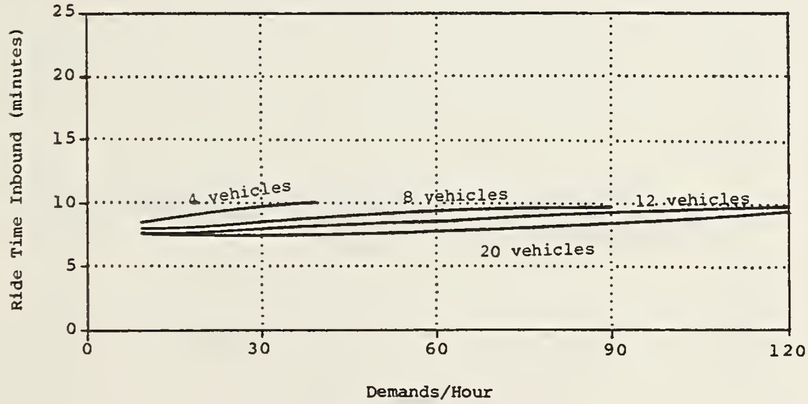


Figure B.12-2

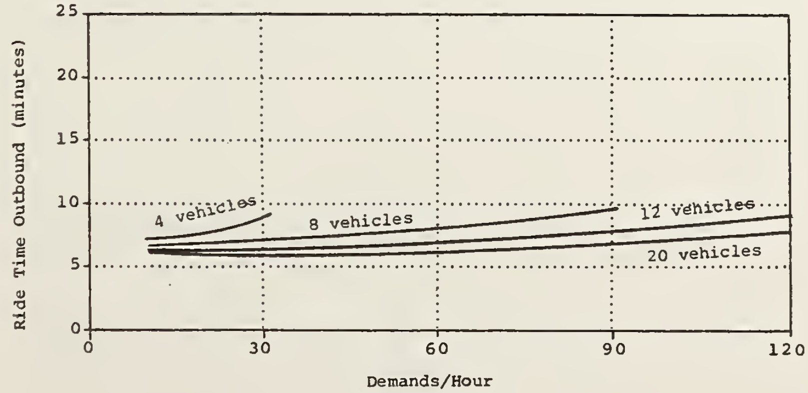


Figure B.12-3

Many-to-One Cycled Service
Area = 4 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 30 minutes

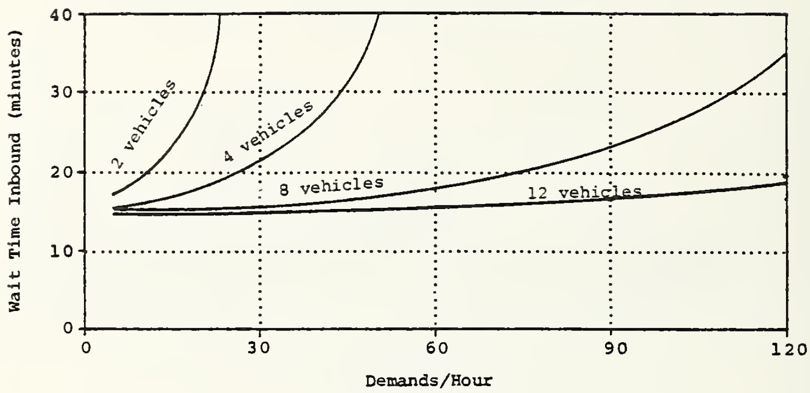


Figure B.13-1

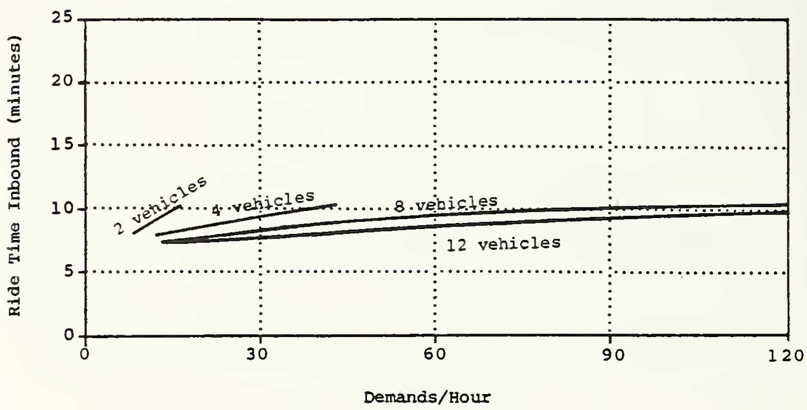


Figure B.13-2

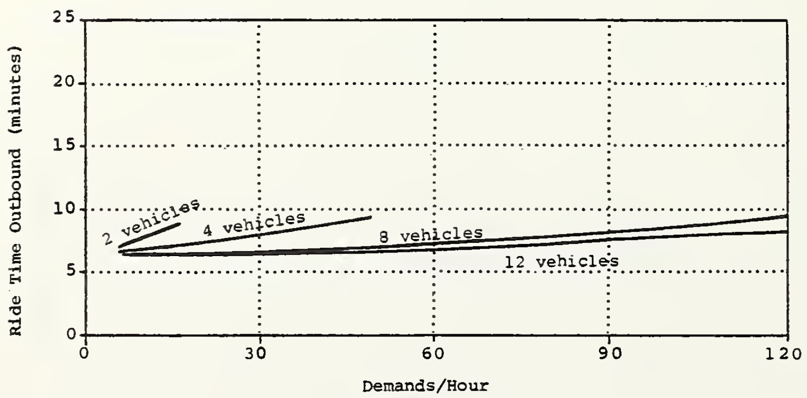


Figure B.13-3

Many-to-One Cycled Service

Area = 6 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 10 minutes

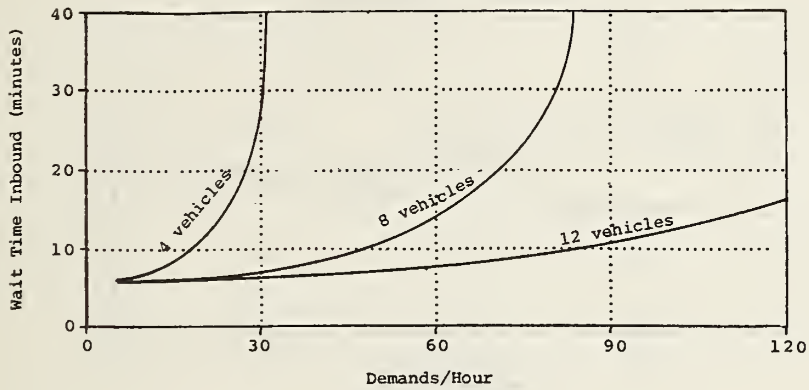


Figure B.14-1

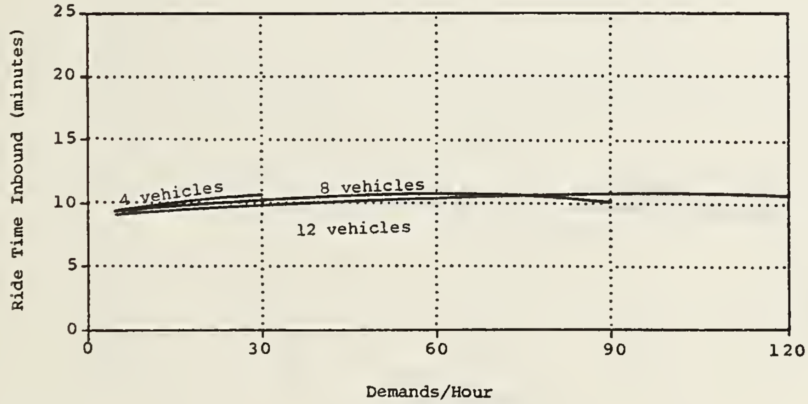


Figure B.14-2

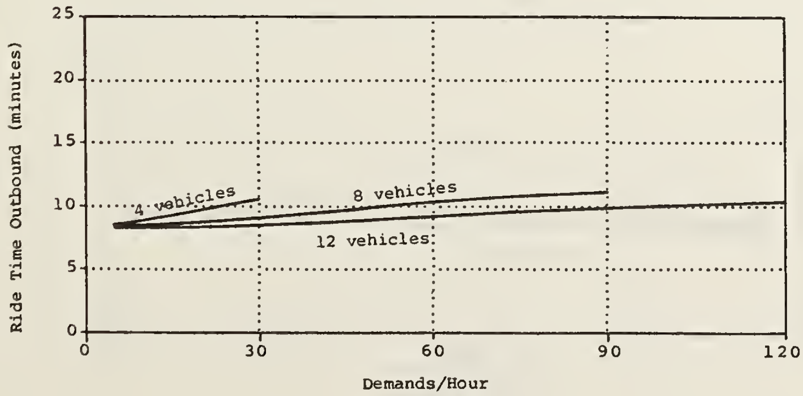


Figure B.14-3

Many-to-One Cycled Service
Area = 6 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 30 minutes

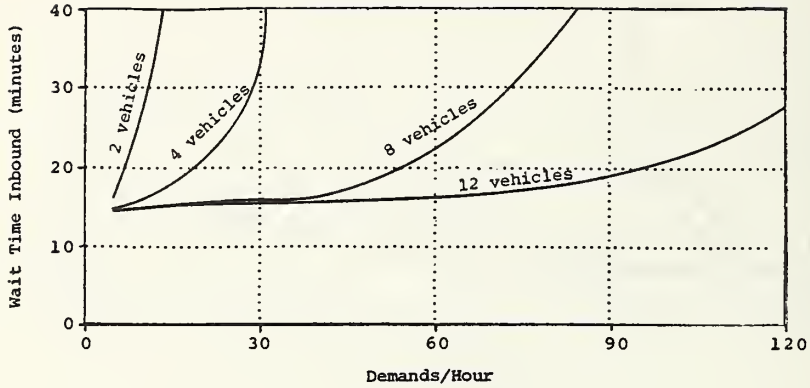


Figure B.15-1

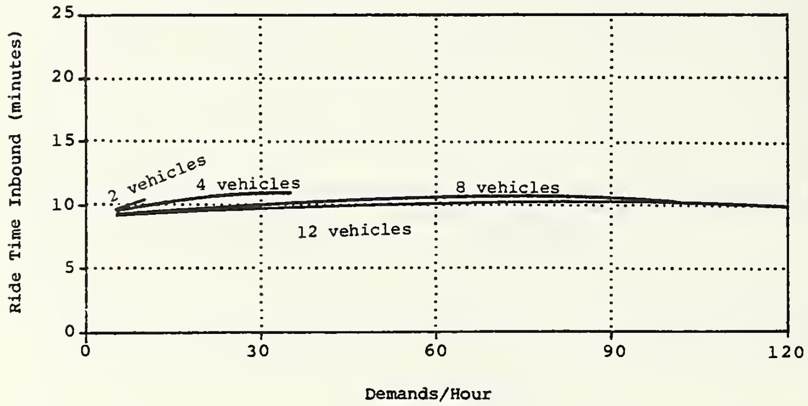


Figure B.15-2

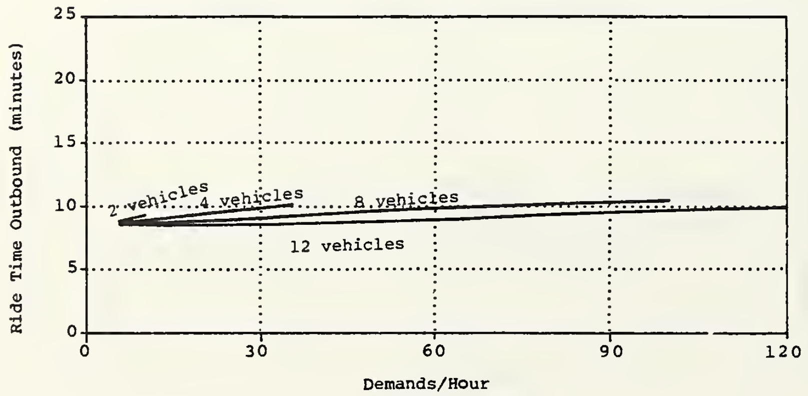


Figure B.15-3

Many-to-One Cycled Service
Area = 6 sq. mi.
Cycle Time = 60 minutes
DRT Headway = 30 minutes

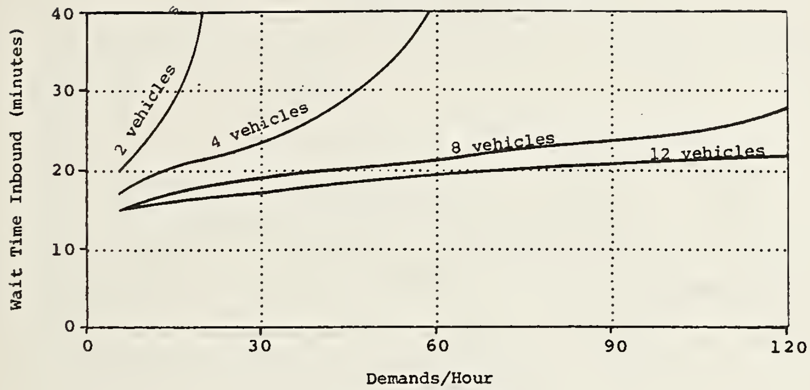


Figure B.16-1

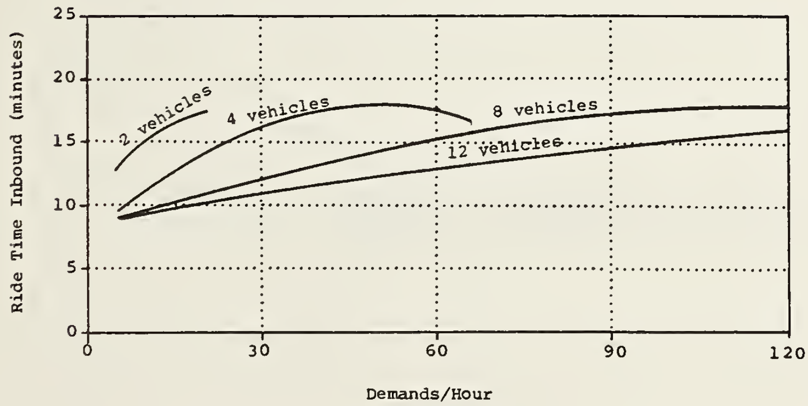


Figure B.16-2

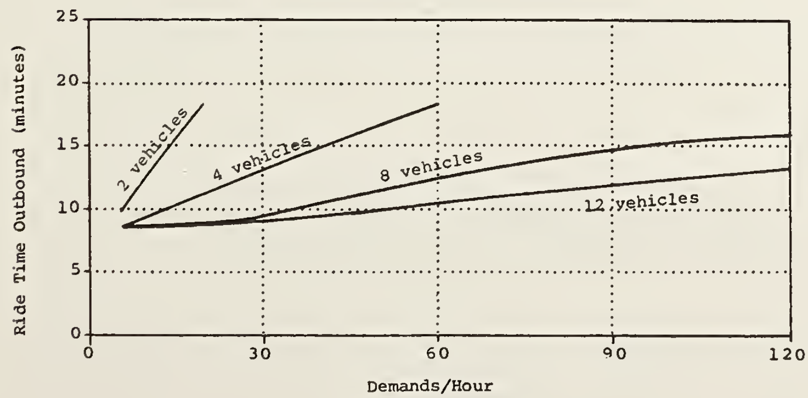


Figure B.16-3

Many-to-One Cycled Service
Area = 8 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 10 minutes

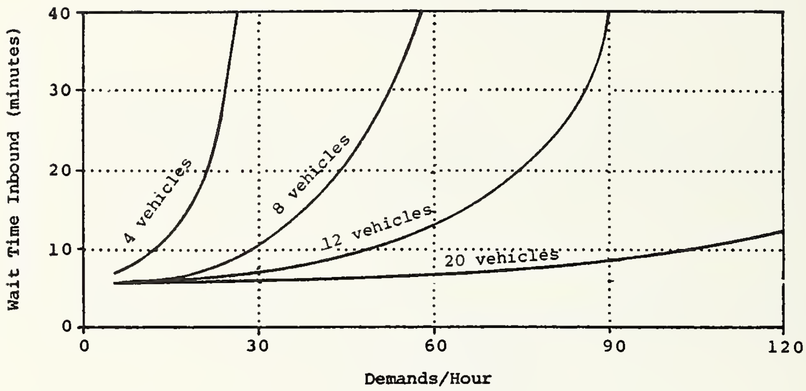


Figure B.17-1

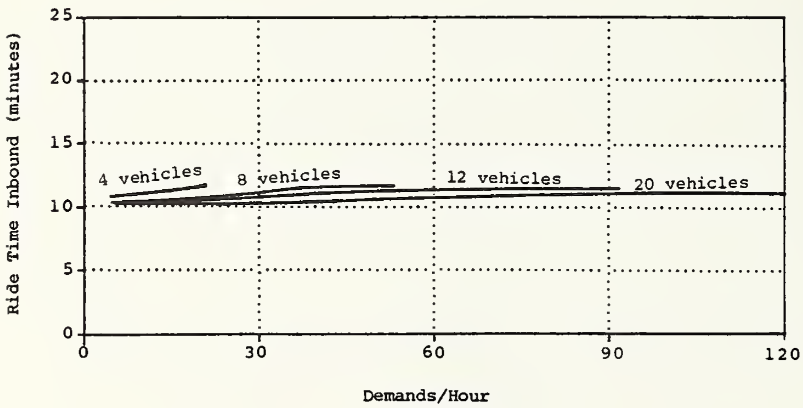


Figure B.17-2

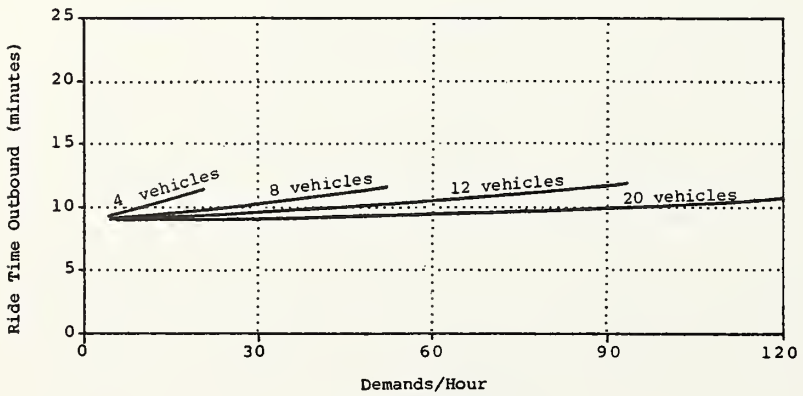


Figure B.17-3

Many-to-One Cycled Service
Area = 8 sq. mi.
Cycle Time = 30 minutes
DRT Headway = 30 minutes

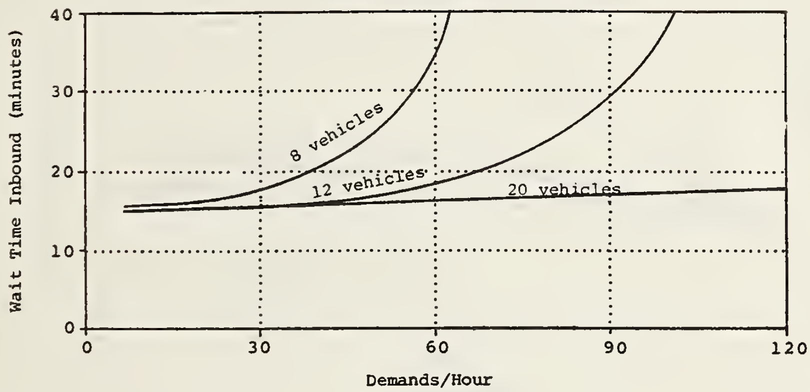


Figure B.18-1

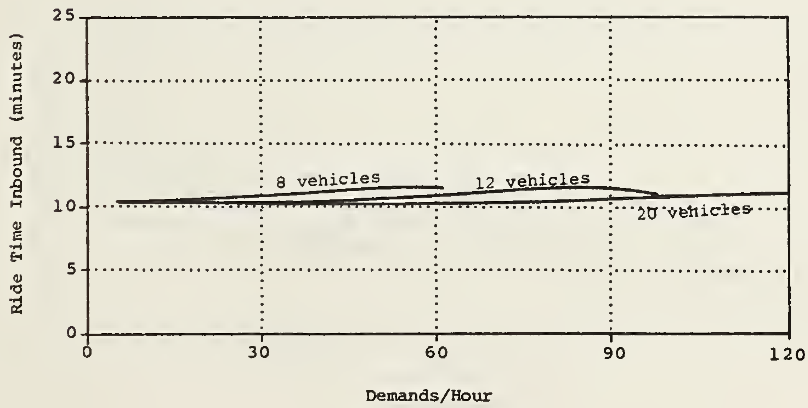


Figure B.18-2

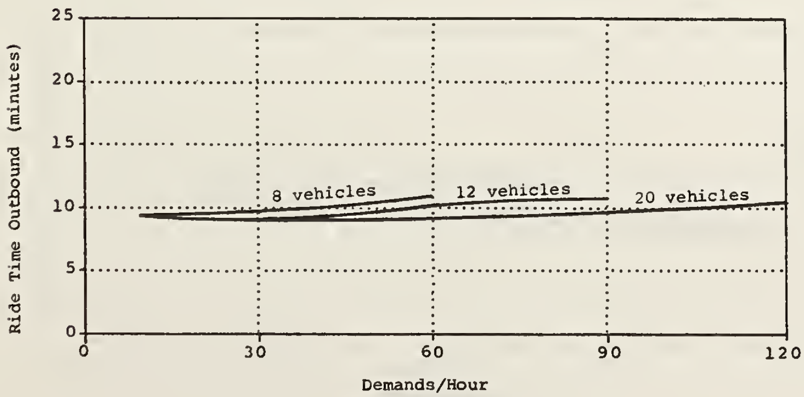


Figure B.18-3

Many-to-One Cycled Service
Area = 8 sq. mi.
Cycle Time = 60 minutes
DRT Headway = 30 minutes

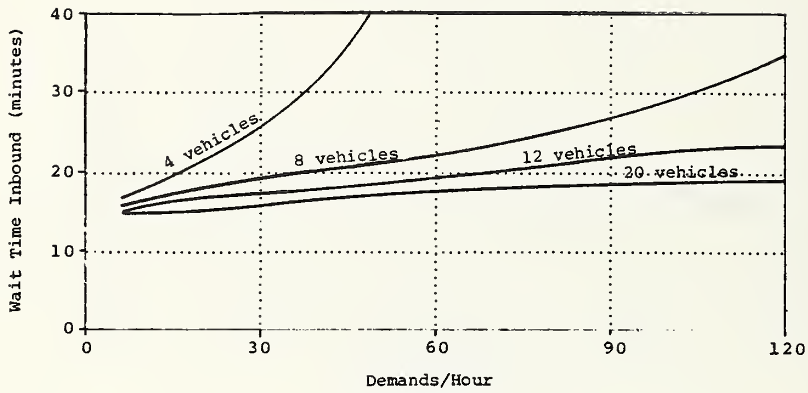


Figure B.19-1

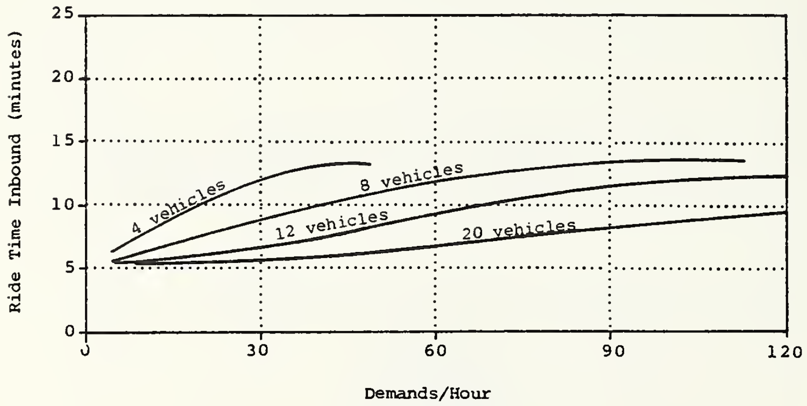


Figure B.19-2

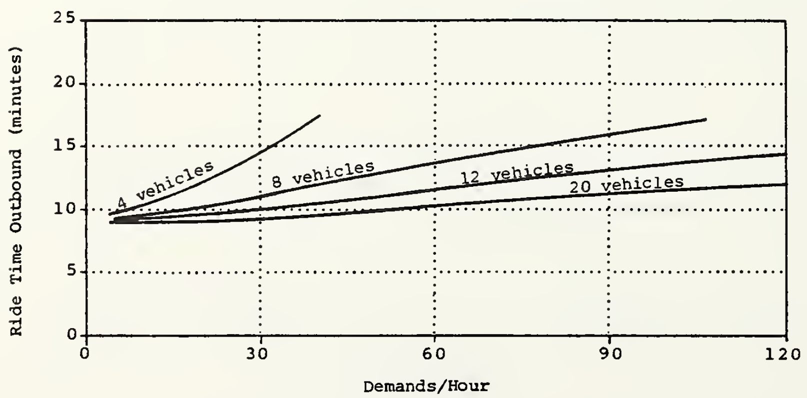


Figure B.19-3

In-Phase/Out-of-Phase Many-to-One Cycled Service Comparison
Area = 4 sq. mi., 8 vehicles
Cycle Time = 30 minutes

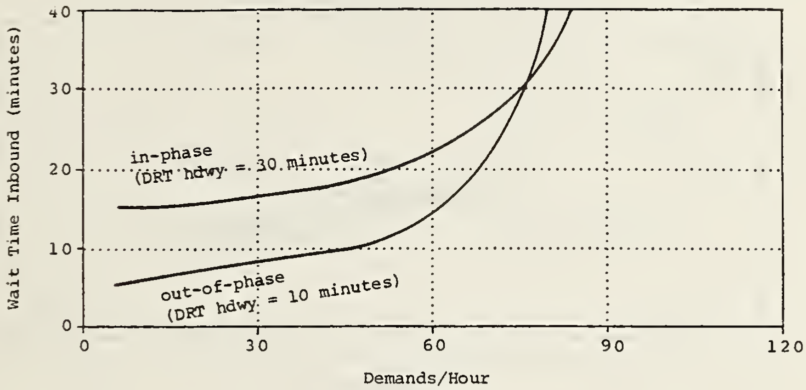


Figure B.20-1

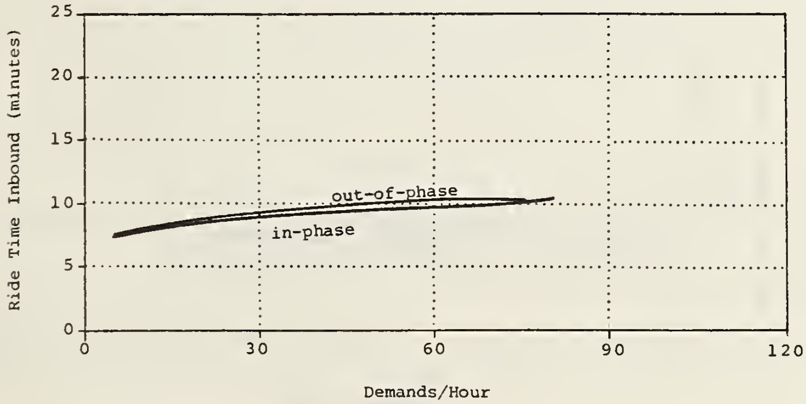


Figure B.20-2

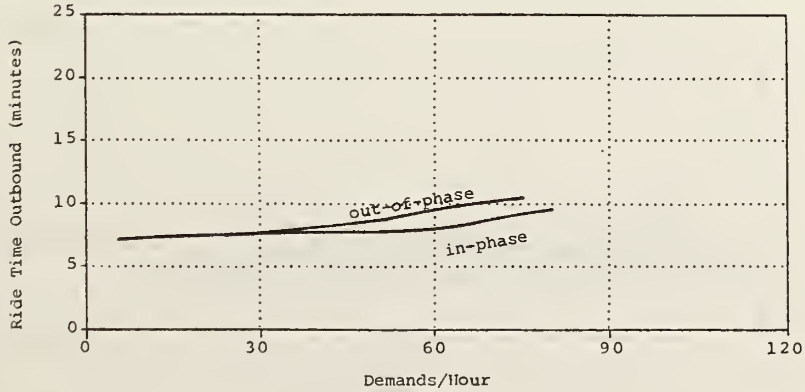


Figure B.20-3

Transfer Point Location in Many-to-One Cycled Service
Area = 4 sq. mi., 6 vehicles
Cycle Time = 30 minutes
DRT Headway = 30 minutes

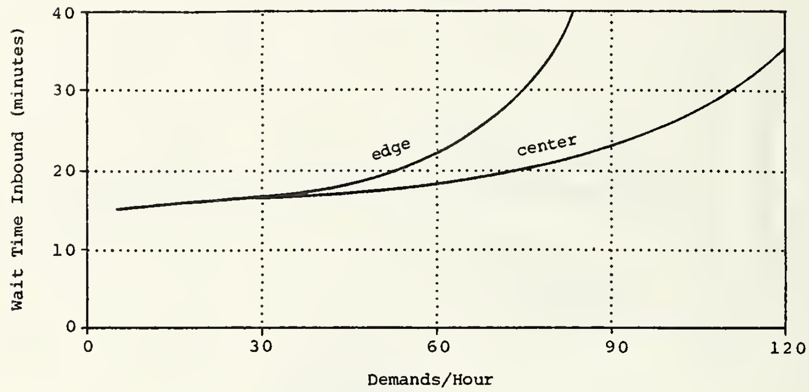


Figure B.21-1

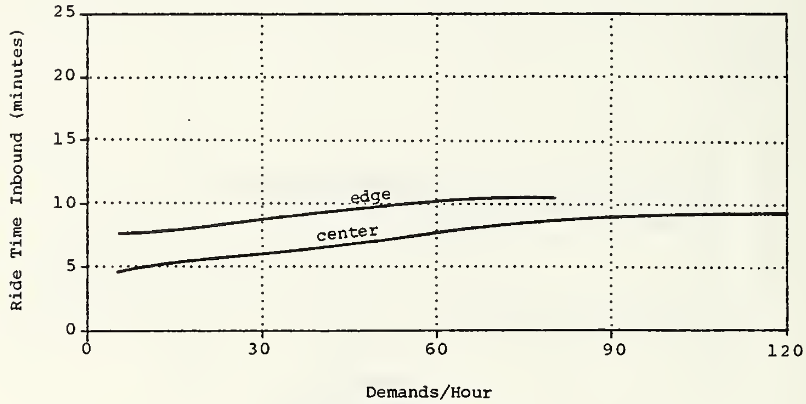


Figure B.21-2

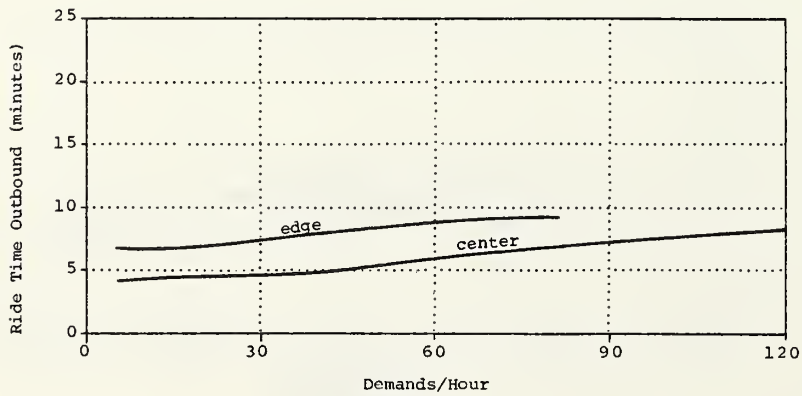


Figure B.21-3

Percent Inbound in Many-to-One Cycled Service
Area = 4 sq. mi., 6 vehicles
Cycle Time = 30 minutes
DRT Headway = 30 minutes

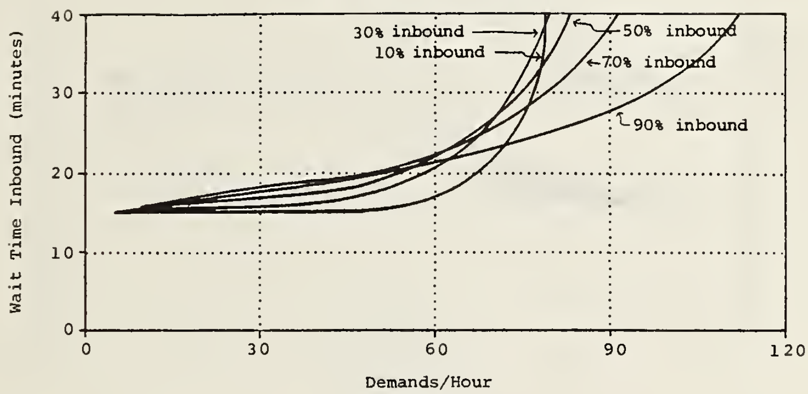


Figure B.22-1

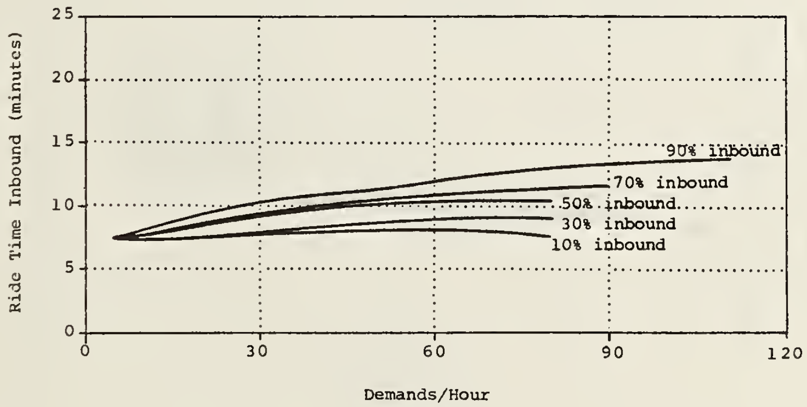


Figure B.22-2

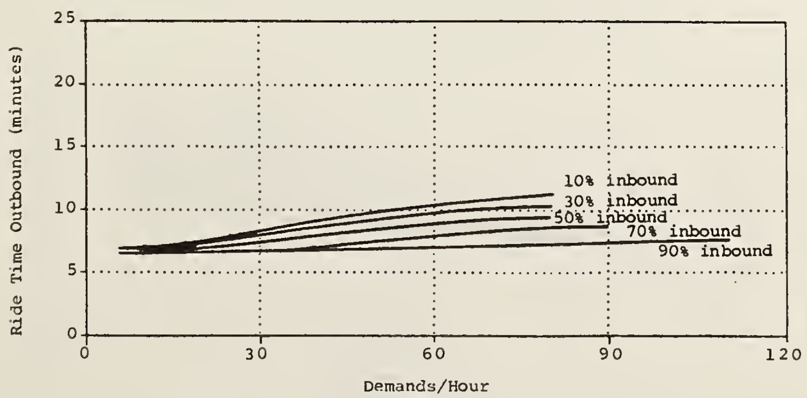


Figure B.22-3

Impact of Many-to-Many Passengers
on Many-to-One Cycled Service
Area = 4 sq. mi., 6 vehicles
Cycle Time = 30 minutes
DRT Headway = 30 minutes

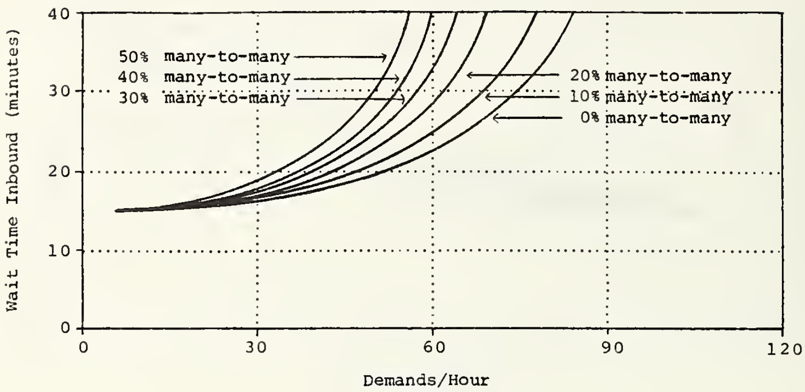


Figure B.23-1

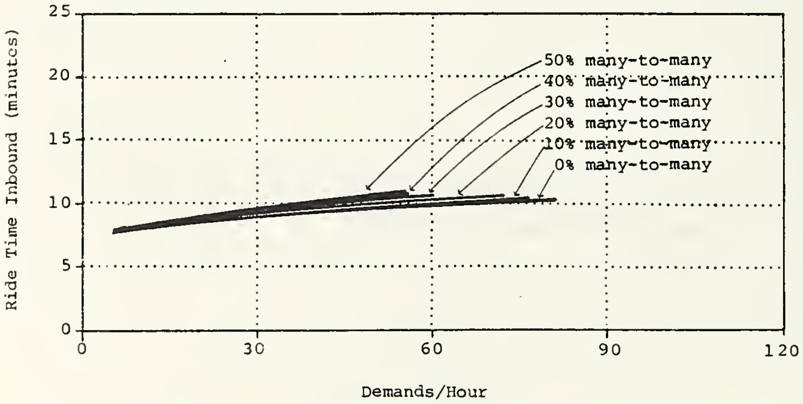


Figure B.23-2

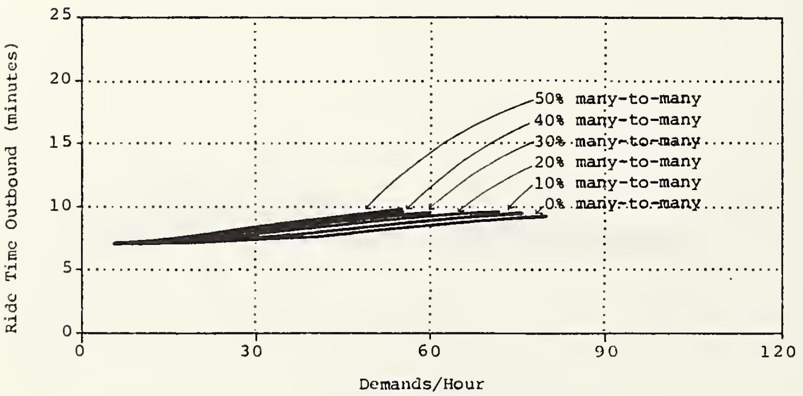


Figure B.23-3

Many-to-One Subscription Service
Area = 2 sq. mi.

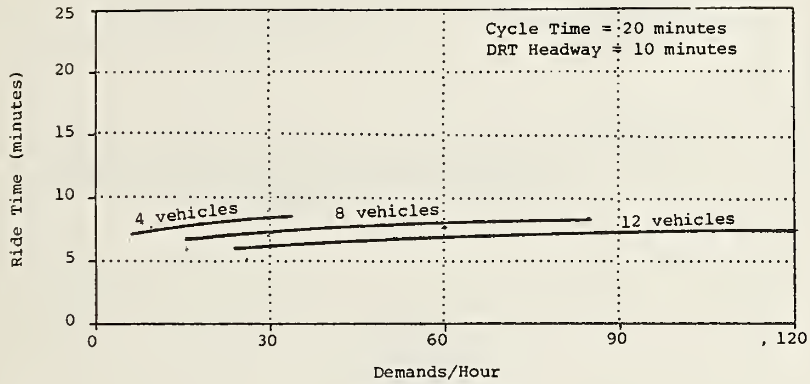


Figure B.24-1

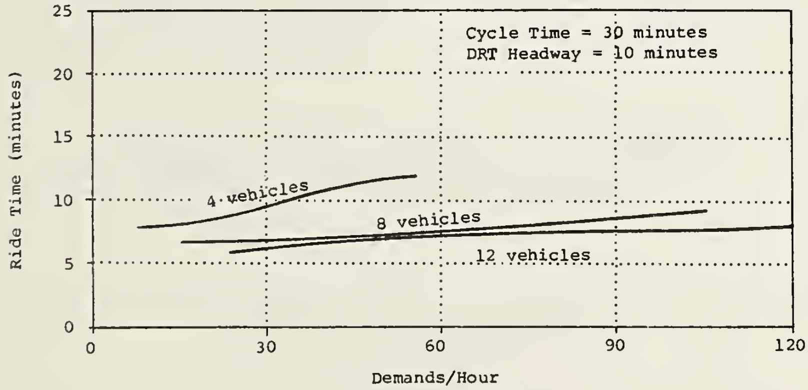


Figure B-24.2

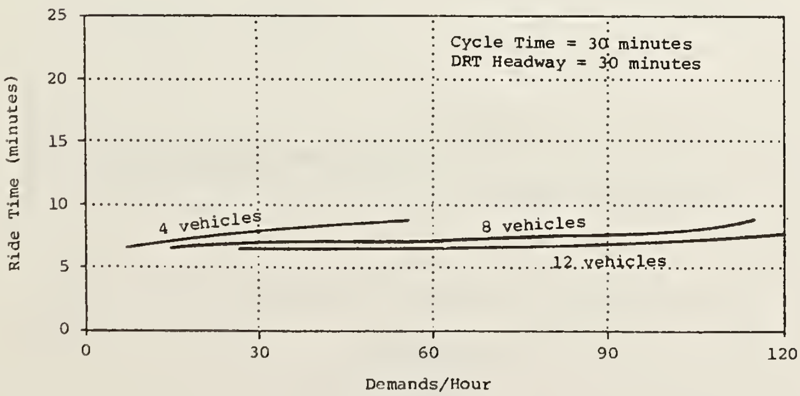


Figure B.24-3

Many-to-One Subscription Service
Area = 4 sq. mi.

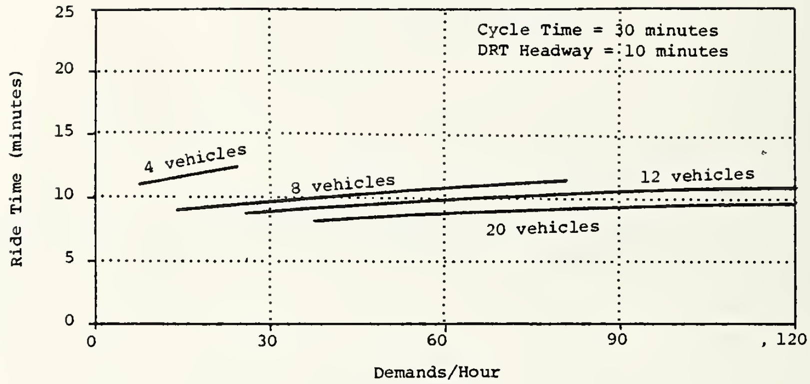


Figure B.25-1

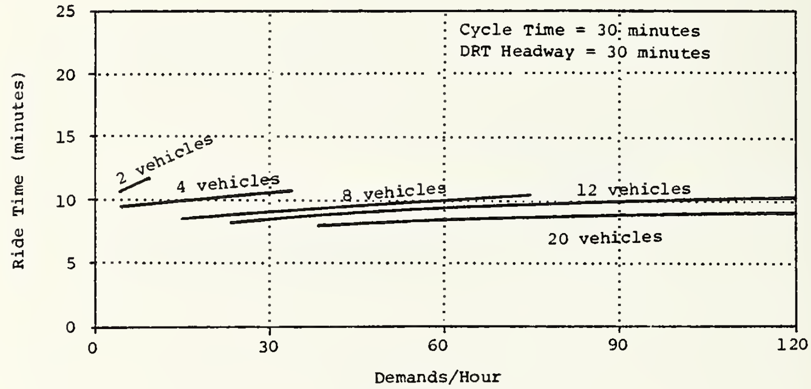


Figure B.25-2

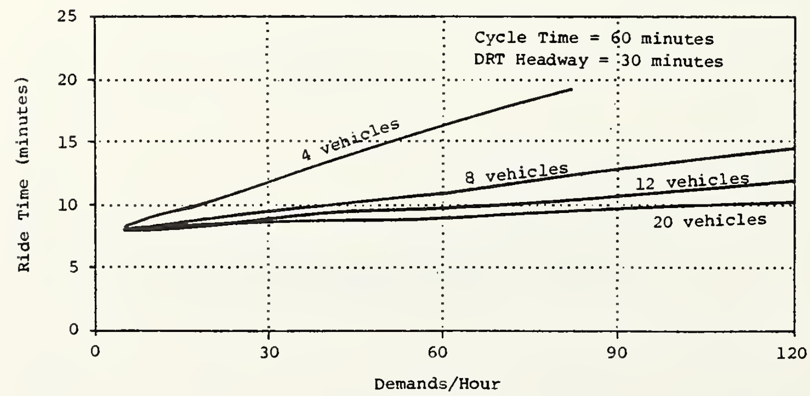


Figure B.25-3

Many-to-One Subscription Service
Area = 6 sq. mi.

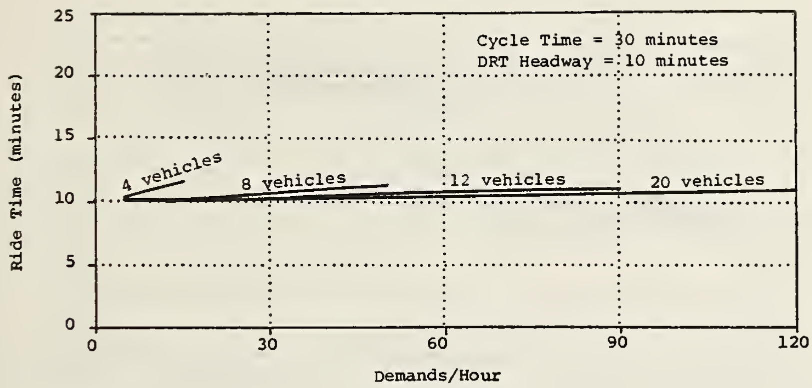


Figure B.26-1

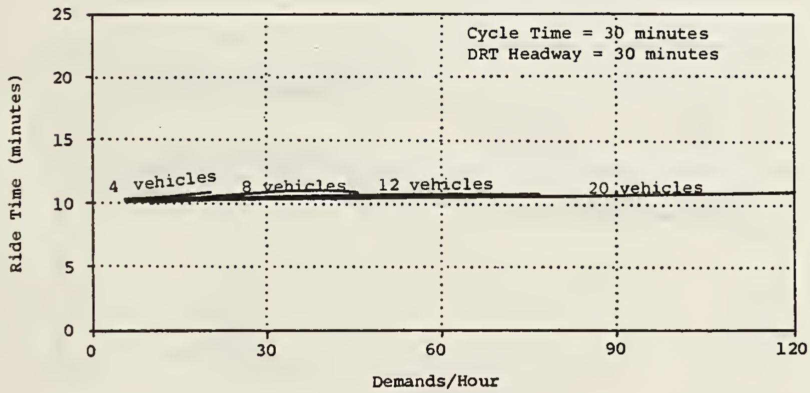


Figure B.26-2

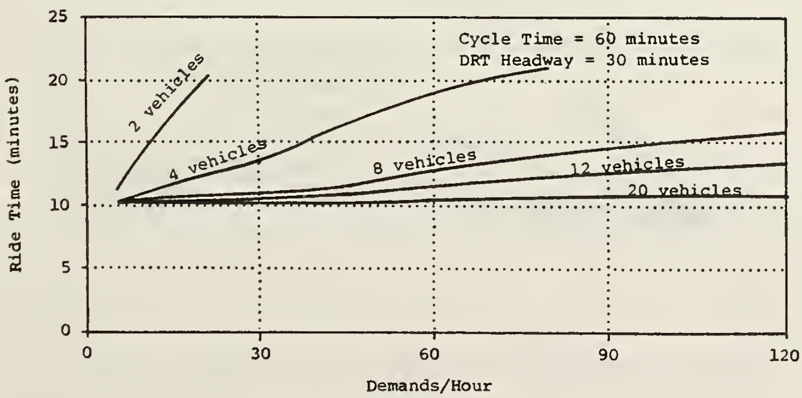


Figure B.26-3

Many-to-One Subscription Service
Area = 8 sq. mi.

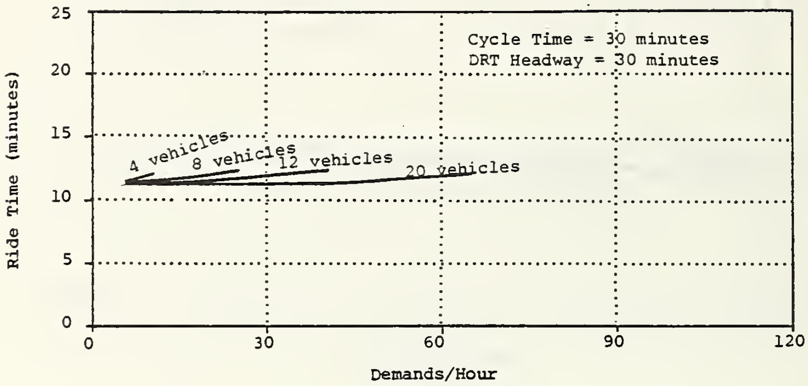


Figure B.27-1

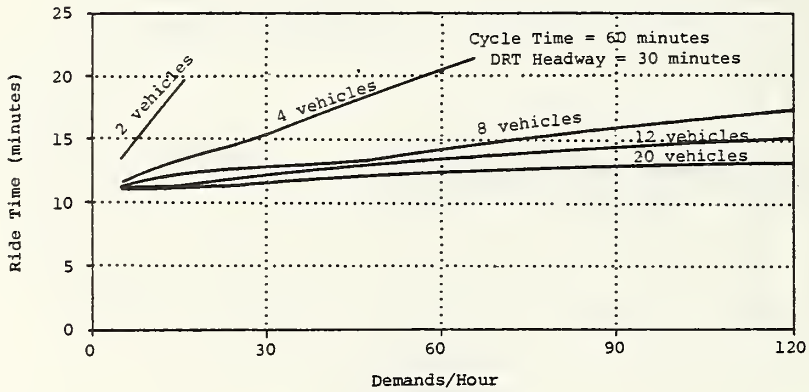


Figure B.27-2

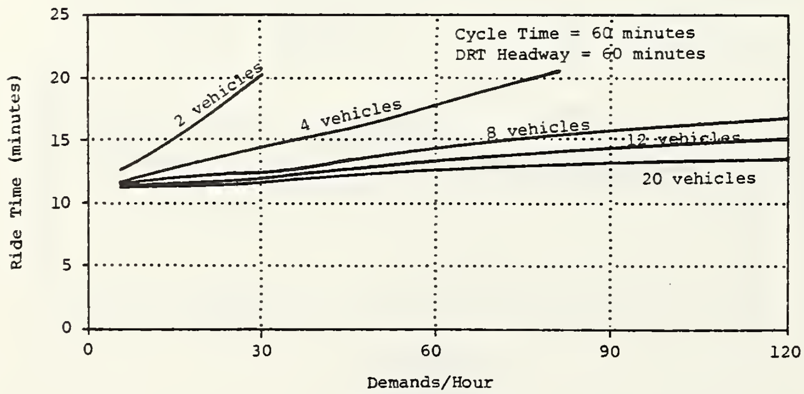


Figure B.27-3

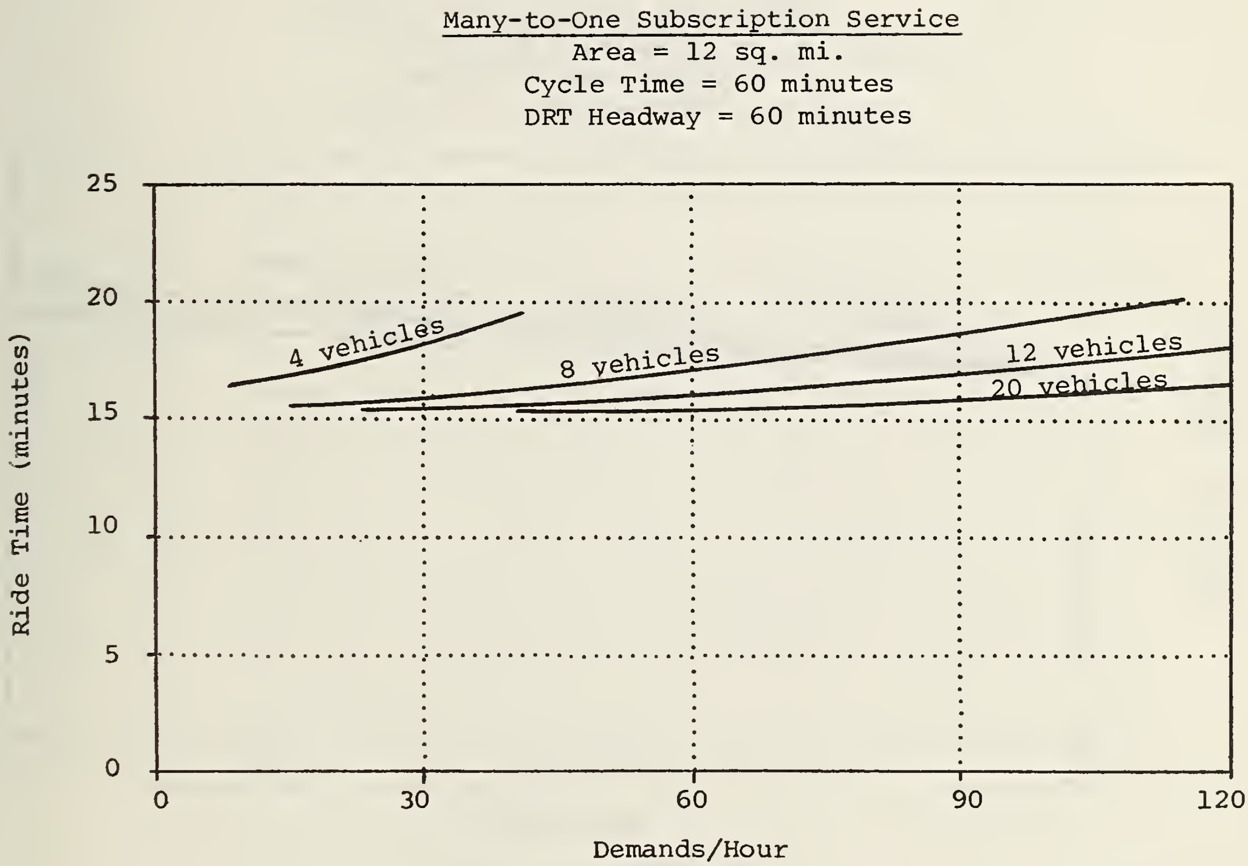

Many-to-One Subscription Service
Area = 12 sq. mi.
Cycle Time = 60 minutes
DRT Headway = 60 minutes
Ride Time (minutes)
25
20
15
10
5
0
0
30
60
90
120
Demands/Hour
4 vehicles
8 vehicles
12 vehicles
20 vehicles

Figure B.28-1

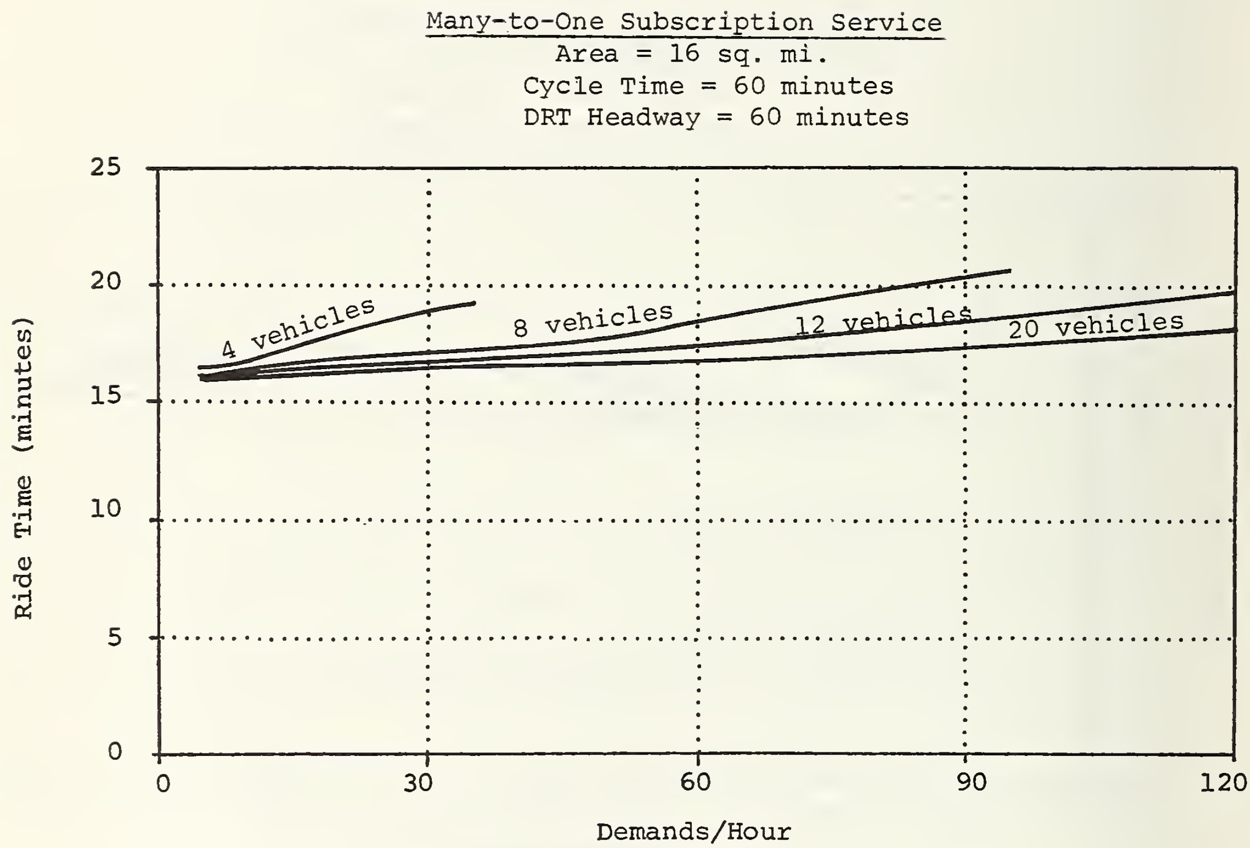

Many-to-One Subscription Service
Area = 16 sq. mi.
Cycle Time = 60 minutes
DRT Headway = 60 minutes
Ride Time (minutes)
25
20
15
10
5
0
4 vehicles
8 vehicles
12 vehicles
20 vehicles
0
30
60
90
120
Demands/Hour

Figure B.29-1

Many-to-One Subscription Service
Area = 20 sq. mi.
Cycle Time = 60 minutes
DRT Headway = 60 minutes

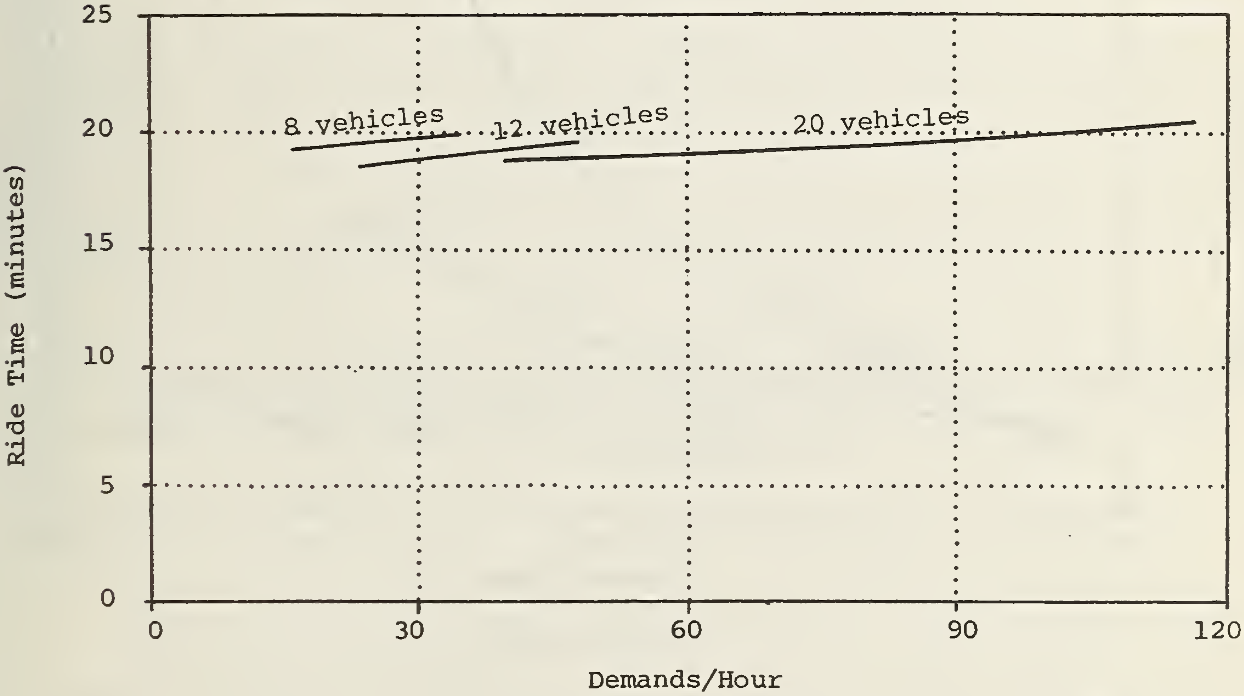


Figure B.30-1

Comparison of DRT Services

Area = 6 sq. mi., 8 vehicles

Cycle Time = 30 minutes

DRT Headway = 10 minutes

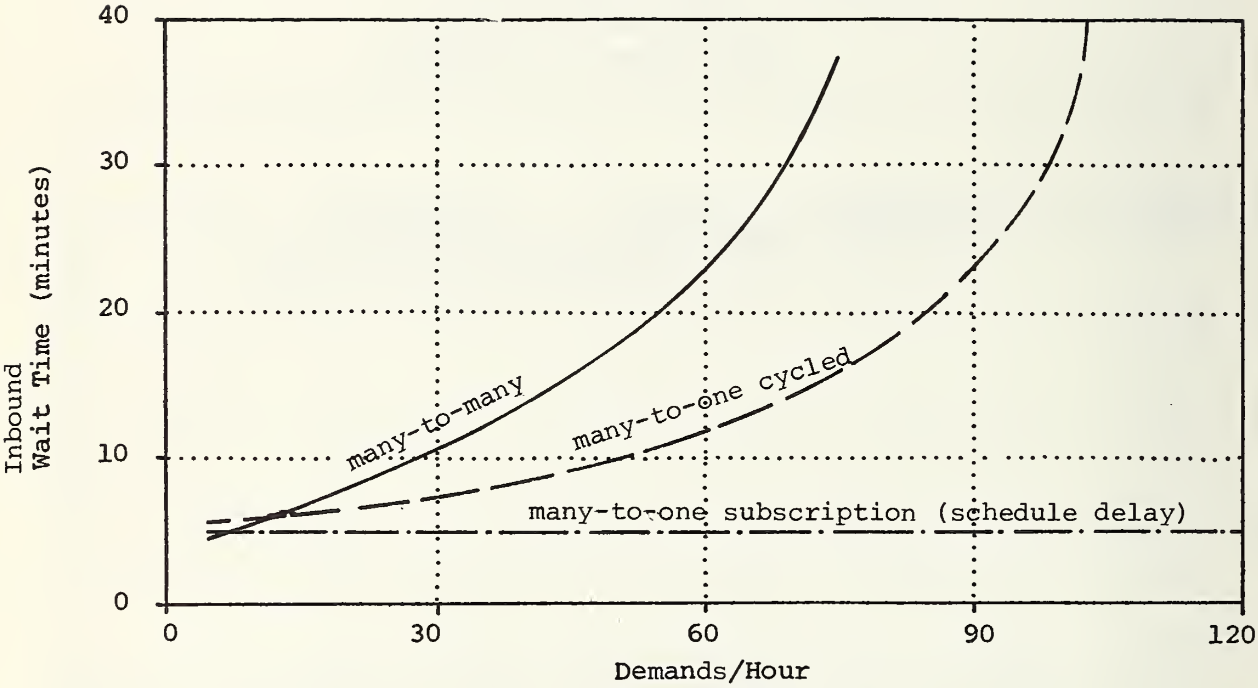


Figure B.31-1

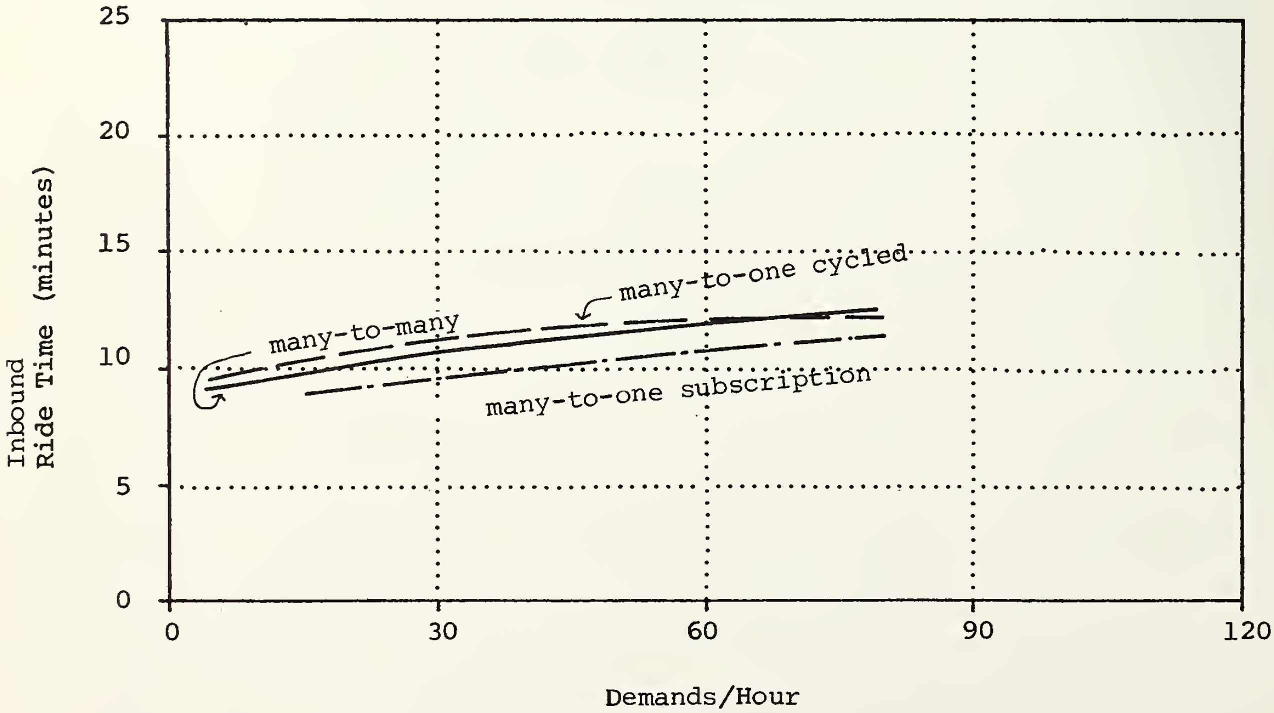


Figure B.31-2

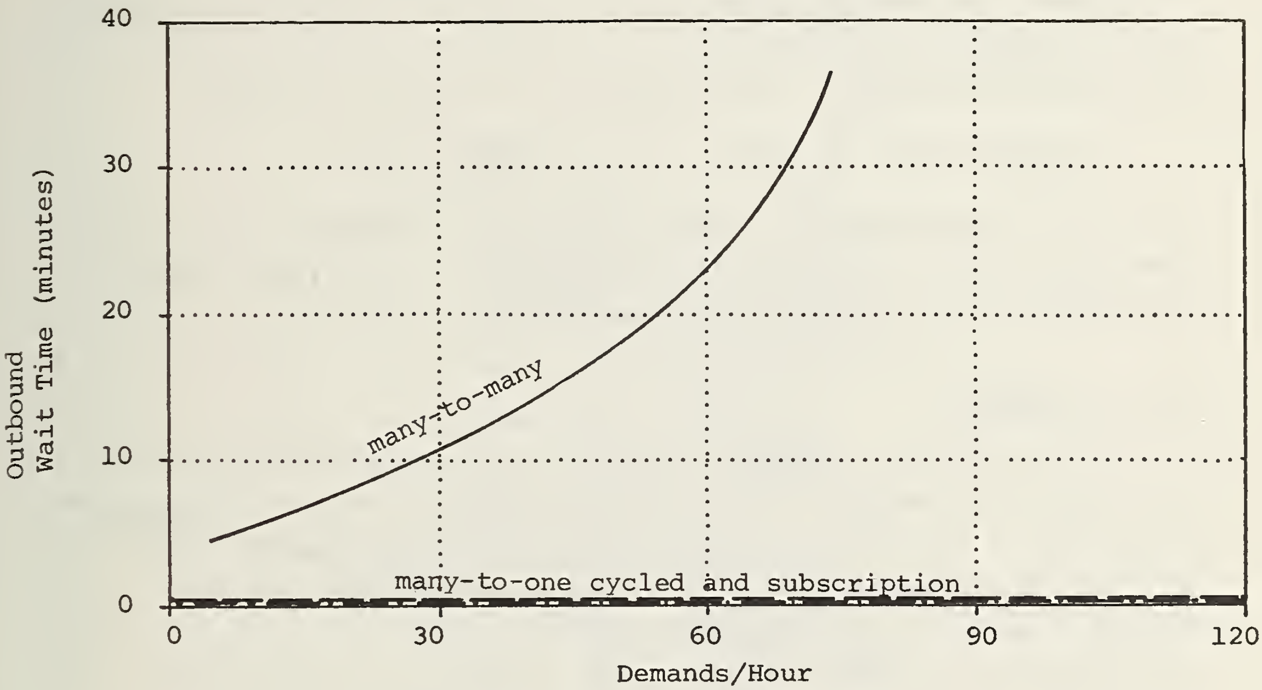


Figure B.31-3

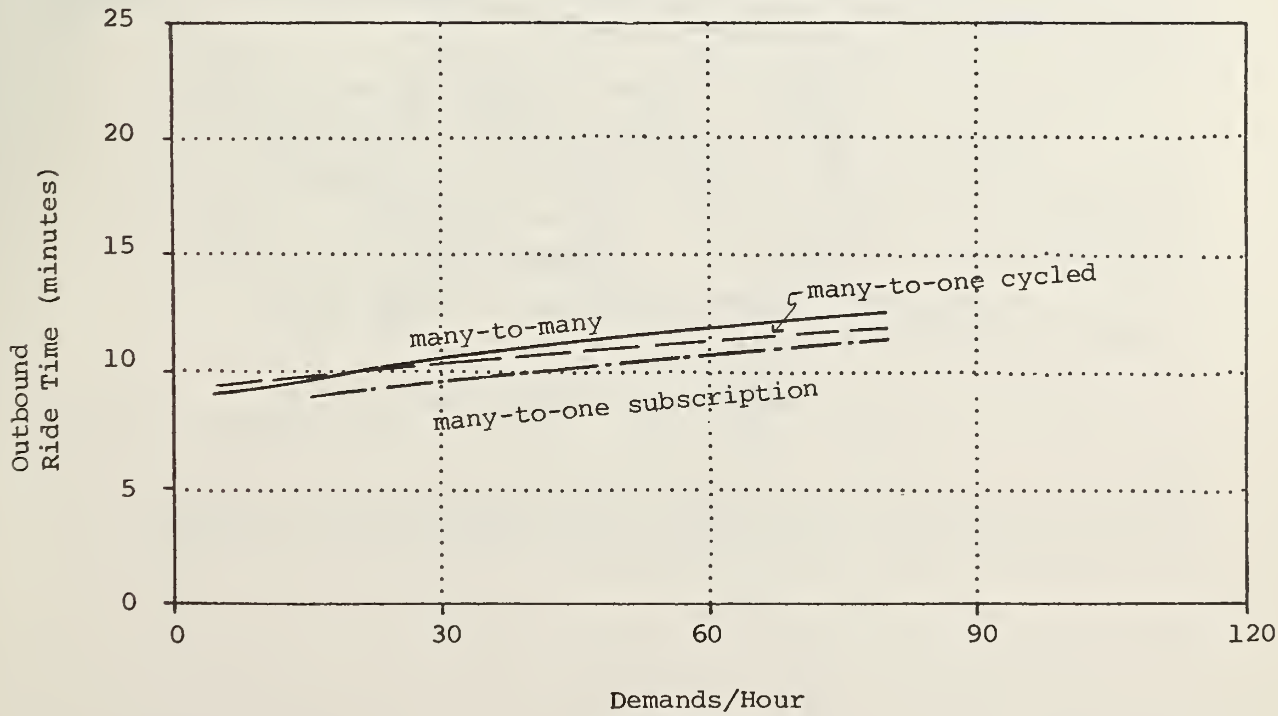


Figure B.31-4

In the cycled and subscription many-to-one services, the adjustment for vehicle speed is more complex. This adjustment can be performed by artificially adjusting the area size for the service analyzed. The adjustment is made as follows:

$$\text{Adjusted area} = \text{area} \times \left(\frac{15 \text{ mph}}{\text{actual base speed}}\right)^2$$

This relationship was developed from a set of actual runs. Note that since there are not nomographs for all area sizes, this adjustment will be approximate, at best.

B.2 Examples

To illustrate the application of the models in analyzing DRT feeder options with UTPS, consider the hypothetical setting presented in Figure B.32. There are two areas in this city in which the transit authority is considering implementing demand-responsive transportation service. Area 1 is being considered for either a many-to-many dynamically dispatched system, or cycled service to feed the conventional transit line during the off-peak. Plans call for implementing a peak hour subscription feeder service in Area 2.

Figure B.33 presents one possible representation of the transit network as coded for use in UTPS.[1] The analysis zones which are included in the proposed DRT service areas are indicated by the symbol ⬡ . Access links to the fixed route system are also shown. Note that Service Area 1 is entirely represented by one analysis zone, while Area 2 contains two analysis zones.

The rest of this section will consist of six examples.

---

[1] This is a very aggregate network description. It has been overly simplified to provide a clearer base network on which to illustrate DRT service analysis.

Figure B.32

Sample DRT Service Area Locations

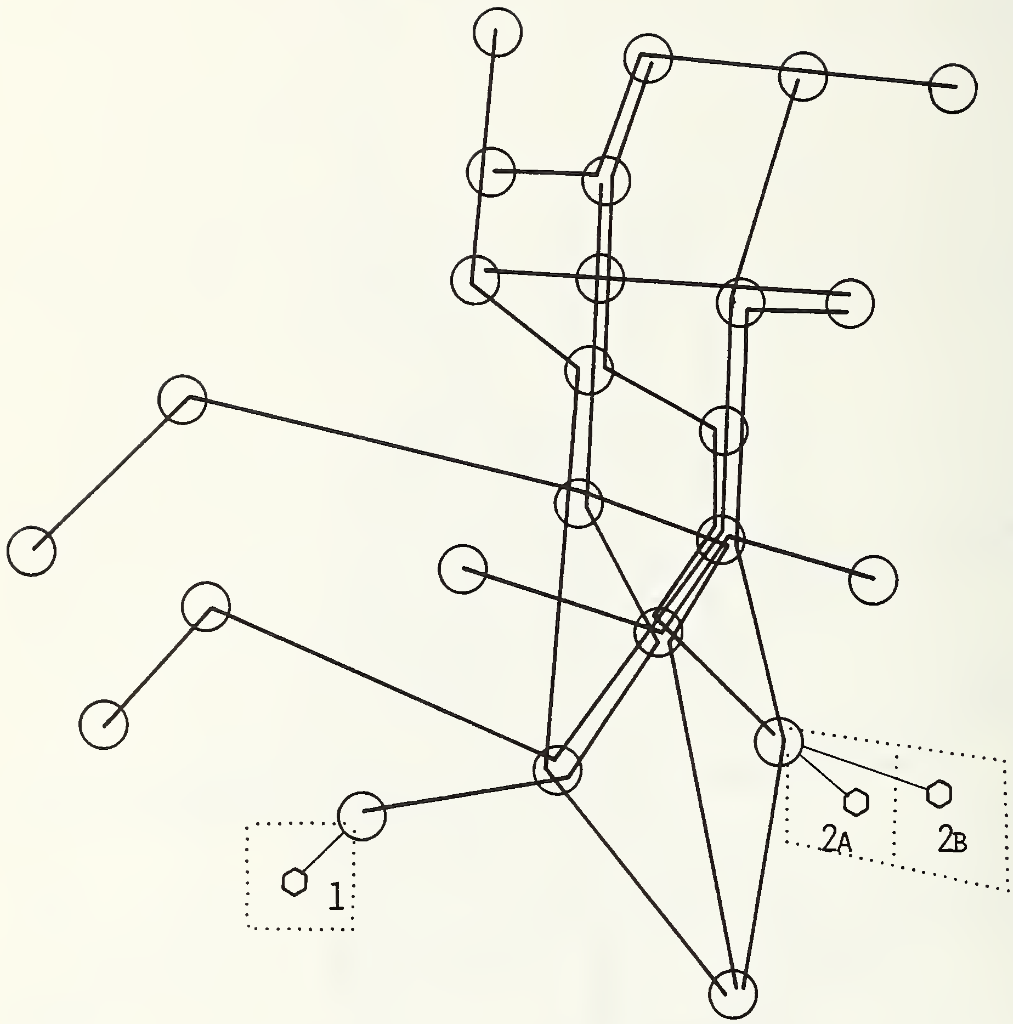


Figure B.33

UTPS Network Representation
of Service Areas

One simple application of each type of service is presented to illustrate the use of the nomographs appearing in the previous section of this appendix. An additional example of each type of service will focus on ways to adjust the results presented in the nomographs to account for service descriptors which differ from those used to develop the nomographs. A step-by-step approach to adjusting each of the various parameters is provided. Because the adjustments will produce only approximate results, a comparison is made between this type of screening result and the results produced by exercising the computer programs.

B.2.1 Example 1. Many-to-Many Service

The characteristics of the many-to-many system proposed for Service Area 1 are:

- Area = 4 square miles
- Vehicle fleet size = 4
- Manual dispatching
- Vehicle speed = 15 miles per hour
- Line haul headway = 30 minutes
- Transfer point located at corner of service area
- Expected patronage = 24 demands/hour (initial estimates, all passengers, not just feeder)
- No advanced requests
- No coordinated transfers

Calculation of Service Times

This system is similar to that of the system represented by Plate M-2. Accordingly, values of wait time and ride time can be taken directly from the (4 vehicle) graphs in Figure

B.2-1 and B.2-2. The ride time figure presented applies to both inbound and outbound. Transfer time inbound can be computed as one-half the headway, or 15 minutes, since there are no coordinated transfers. For this example, it is assumed that the request for distributor service is made on board the line haul vehicle; hence, transfer time outbound is set at 2 minutes, representing the uncertainty of DRT and line vehicle arrival times. All service level values are shown in Table B.3.

Table B.3. Service Times for Example 1

Direction of Travel	Wait Time (at Home)	Ride Time	Transfer Time
Inbound	14.5 min	7.8 min	15 min
Outbound	--	7.8 min	2 min

Calculation of Access/Egress Times

Given these service times, access and egress times can be calculated as follows.

$$A = RUN \times 7.8 + WAIT \times 14.5$$

$$E = RUN \times 7.8 + WAIT \times 2$$

where RUN and WAIT are the user-supplied weights on ride and wait time respectively, as discussed in Chapter 4.

Note that inbound transfer time is ignored in the access time, since UTPS will automatically calculate that time as the wait time for the line haul service.

Input/Output Reconciliation

To illustrate the interrelationship between demand and supply in a DRT system, consider what happens after the UTPS

analysis has been completed, and a sub-modal split routine is used to estimate the demand for the DRT feeder service. Recall that an initial estimate of 24 demands/hour for the DRT system was provided. Let us assume that it was estimated that 21% of these demands, or 5 demands/hour, were feeder demands, equally divided in the inbound and outbound directions. Suppose that, after the UTPS and sub-model split analysis, it was predicted that there were 17 feeder demands per hour. Assuming the intra-service area demand is an exogenous input which remains the same, the total demand rate would now be 36 demands per hour. Theoretically, one could choose to use this as the new initial demand estimate, rerun the complete UTPS analysis, and continue to iterate until the input and output demand values are essentially the same. Clearly, however, this could be a very costly and time consuming process. It can be avoided in cases where the size of the vehicle fleet is a variable which can be changed. Given the (output) demand rate of 36 demands/hour, return to Plate M-2 and find the vehicle fleet size for which ride time is approximately 7.8 minutes, and wait time approximately 14.5 minutes (the values which result in the demand predicted of 36 demands/hour). In this case, the resulting vehicle fleet size is 6 (halfway between the 4 and 8 vehicle lines). This type of procedure can be followed in other, similar cases.

B.2.2 Example 2. Many-to-Many Service (Adjustments Required)

The service represented in this example is similar to that of Example 1, with the exception that the DRT service is computer dispatched and accepts advanced requests. In addition, travel patterns from this area indicate that the average travel distance to the transfer point is less than would be assumed for an average system. The system descriptors are:

- Area = 4 square miles
- Fleet size = 4
- Computer dispatched
- Average vehicle speed = 15 miles per hour
- 30% of demands are expected to request service in advance
- Average trip distance to the transfer point is 1.1 miles (instead of 1.276 for an average system)
- Expected patronage is 24 demands per hour

Calculation of Service Time

The steps involved in the calculation of service time are described below.

Step 1 -- Obtain wait and ride time estimates for a 4 sq mile service area from nomograph in Plate M-2

These are the same as those presented for Example 1.

Step 2 -- Adjust wait time and ride time for computer dispatching

- Wait time computer = wait time manual/$(1 + \alpha + \beta)$
  = 14.5/(1+.5+.2) = 8.5 minutes
- Ride time computer = ride time manual + β(wait time
  = computer) = 7.8+0.2(14.5)= 10.7 minutes

Step 3 -- Adjust for difference in average trip distance to transfer point

- Ride time adjusted = ride time (actual average trip distance)/(trip distance assumed in nomograph)
  = 9.5 (1.1 miles)/(0.638 $\sqrt{\text{Area}}$)
  = 9.5 (1.0/1.276)
  = 8.2 minutes

Step 4 -- Adjust for advanced requests

Table B.2 provided a set of factors for adjusting wait and ride time based on the percent of advanced requests and the productivity. Since 24 demands per hour served by four vehicles

is a productivity of 6, the advanced request adjustment factors used are 0.16 for wait time and 0.09 for ride time.

- Wait time with advanced requests = wait time without advanced requests + wait time factors (Total time without advanced requests) = 8.5 + 0.16(8.5 + 8.2) = 11.2 minutes

- Ride time with advanced requests = ride time without advanced requests + ride time factor (total time without advanced requests) = 8.2 + 0.09(8.5+8.2) = 9.7 minutes

The final adjusted level of service characteristics are presented in Table B.4 below.

Table B.4.* Service Times, Example 2

	Wait Time at Home	Ride Time	Transfer Time
Inbound	11.2 min (11.2)	9.7 min (10.3)	15 min (15)
Outbound	--	9.7 min (10.3)	2 min (2)

*computer modeled results in parentheses

Calculation of Access and Egress Time

Calculation of access and egress times proceeds in the same fashion as in Example 1.

B.2.3 Example 3 - Many-to-One Cycled Service

An alternative to many-to-many service in Service Area 1 is many-to-one cycled service. In this example a pure many-to-one service with all passengers travelling either to or from the transfer point is assumed. Furthermore, it is assumed that there are an equal number of inbound and outbound passengers. System characteristics for this example are:

- Area = 4 sq miles
- Vehicle fleet size = 4

- Vehicle speed = 15 miles per hour
- Transfer point located at the corner of the service area
- Fixed route headway is 30 minutes and each fixed route bus is met by all 4 DRT vehicles (i.e. cycle time = 30 minutes, feeder headway = 30 minutes)
- DRT vehicles have a scheduled 3 minute layover at the transfer point to insure reliable service
- No many-to-many passengers are served
- 50% of passengers travel inbound and 50% travel outbound
- Expected demand level is 24 per hour

Calculation of Service Times

Wait and ride time for this system can be read directly from Plate O-4. Three graphs are presented to indicate wait time inbound, ride time to the transfer point, and ride time from the transfer point. Outbound transfer time is calculated as one-half the layover time. The resulting service times are shown in Table B.5.

Table B.5. Service Times - Example 3

	Wait Time	Ride Time	Transfer Time
Inbound	18.5 min	9.2 min	1.5 min
Outbound	--	7.8 min	1.5 min

Calculation of Access and Egress Times

Access and egress times for this service are calculated as follows:

A = RUN x 9.2 + WAIT x 18.5 + WAIT (1.5 - 15)

E = RUN x 7.8 + WAIT (1.5)

where RUN and WAIT are as before (and WAIT is the same for both line haul and feeder services).

Note that, in this example, a term of (-WAIT x 15) is built into the calculation to compensate for the automatically calculated line haul wait time. As noted in Section 4.2, this compensating factor is unnecessary if the programs being used allow the "first" line haul wait time to be ignored for specific links.

B.2.4 Example 4 - Many-to-One Cycled Service Adjustments Required

The analysis of many-to-one cycled services using the nomographs can become quite complex when some of the restrictions placed on service in Example 3 are eliminated. In this example, many-to-many patrons are allowed to use the DRT cycled service, and demands are not assumed to be equally distributed between inbound and outbound trips. Instead, it is assumed that the majority of trips are inbound, as might be the case during the AM peak period. Another difference between this example and the previous one is the location of the transfer point, which is now located beyond the service area boundary. Service parameters for this example are:

- Area = 4 sq miles
- Vehicle fleet size = 4
- Vehicle speed = 15 miles per hour
- Transfer point located 3 <u>minutes</u> outside the service area
- Headway of fixed route = 30 minutes
- All DRT vehicles meet all fixed route vehicles (feeder headway = cycle time = 30 minutes)

- Layover time = 3 minutes
- 80% of passengers are traveling to the transfer point (inbound)
- 10% of passengers are traveling from the transfer point (outbound)
- 10% of passengers are traveling within the service area (many-to-many)
- expected demand level is 24 demands per hour.

Calculation of Service Time

The steps in the calculation of service time are described below.

Step 1 -- Adjust demand characteristics for many-to-many passengers

Since each many-to-many demand requires both a pickup and dropoff in the service area, they have the impact of two demands.[1]

- Adjusted demand level = (1 + % many-to-many) x demand level = (1 + 0.1) 24 = 26.4 demands/hour
- Adjusted inbound percent = (inbound + % many-to-many)/ (1 + % many-to-many) = (0.8 + 0.1)/1.1 = 0.82
- Adjusted outbound percent = 1 - adjusted inbound percent = 1 - 0.82 = 0.18.

Step 2 -- Adjust for transfer point location

Since 6 minutes of run time must be used outside the service area, not all the available cycle time can be used to pick up and drop off passengers. To adjust for this factor, the effective demand level is increased, as if this time were spent serving demands. The number of demands which must be added depends on the amount of time spent outside the service area, and the demand levels at which vehicle tour becomes full. The demand level at which the vehicle begins to fill its tour occurs approximately at the point at which the wait time curve begins to rise sharply. In this case, the "knee" in the wait time curve occurs at approximately 35 demands per hour (see Figure B.13-1). The adjustment is then made as follows:

---

[1] This adjustment assumes half the stops for serving many-to-many patrons are made on the collection tour and half on the distribution tour. Implementation of other assumptions is straightforward.

Adjusted demand level = (demand level + demand level at "knee") x (additional mean time to get to transfer point)(cycle time)

= 26.4 + 35 (6/30)

= 33.4 demands per hour.

Step 3 -- Adjust for difference in inbound/outbound percent

This adjustment is somewhat complicated to make. The methodology will be presented concisely below without attempts at justification. Note that this is only an approximate technique, employed to avoid using the full model to calculate level of service characteristics.

- Adjusted inbound demand level = 2 x demand level x (% inbound)

  = 2(33.4)(.82) = 54.8

- Adjusted outbound demand level = 2 x demand level x (% outbound)

  = 2(33.4)(.18) = 12.0.

Step 4 -- Calculate ride times

See Figure B. to determine ride times inbound and outbound based on adjusted inbound and outbound demand levels. Note that inbound ride time figures may be extrapolated assuming that the maximum possible average ride time is one-half the available time (cycle minus layover). Outbound ride time cannot be extrapolated. If the graph were to indicate that no service at that adjusted outbound demand level were possible, the service would be infeasible. In this case, however, that does not occur. The additional 3 minute line haul time to the transfer point must be added to the ride time results. Therefore,

- Inbound ride time = 10.4 min + 3 min = 13.4 min
- Outbound ride time = 7.0 min + 3 min = 10 min.

Step 5 -- Calculate inbound wait time

If the adjusted demand level (overall) is less than the demand level at the "knee" of the graph, the wait time can be read directly from the graph. This does occur in this case; therefore (from Figure B.13-1):

Wait time inbound = 22.5 minutes

Table B.6. Service Times, Example 4

	Wait Time	Ride Time	Transfer Time
Inbound	22.5 min (22.9)	13.4 (13.5)	1.5 min (1.5)
Outbound	--	10.0 (10.1)	1.5 min (1.5)

*computer modeled results in parentheses

Calculation of Access and Egress Time

Access and egress times are calculated as in Example 2, using the adjusted values for wait and ride time.

B.2.5 Example 5 - Many-to-One Subscription Service

This example illustrates the coding of subscription service level of service, and the method for considering multiple analysis zones in a single service area. Service Area 2 consists of two separate analysis zones which combine to cover 8 square miles. The characteristics of this service area are:

- Area = 8 sq miles
- Vehicle fleet size = 4
- 15 mph average speed
- Transfer point located as indicated in Figure
- Fixed route headways of 30 minutes
- DRT vehicles operate on 60 minute cycles with half of the fleet meeting each line haul vehicle (out-of-phase operation, DRT headway = 30)
- A 3 minute layover at the transfer point
- Demand rate = 40 demands/hour (combination of both analysis zones)

Calculation of Service Time

All level of service characteristics are constant except for the ride time. Wait time at the transfer point is 1½ minutes, both inbound and outbound. Schedule delay is 15 minutes, or one-half the headway of the fixed route. Ride time inbound and outbound are the same, and can be taken from Figure B.25-3. Service times for this example are shown in Table B-7.

Table B.7. Service Times, Example 5

	Schedule Delay	Ride Time	Transfer Time
Inbound	15 min	17.9 min	1.5 min
Outbound	--	17.9 min	1.5 min

Calculation of Access and Egress Time

Before calculating access and egress times for this example, it is necessary to separately estimate ride time for the two analysis zones. The ride time estimate appearing in Table B.7 is the average ride time over both analysis zones. To estimate the ride time in each analysis zone, let us assume that the mean ride time is proportional to access link distance. Assume further that the access link in analysis zone 2B is 3 times as "long" (as measured on a map) as the access link in zone 2A, but that the demand for service is the same for both zones. Ride time for zone 2A and 2B can then be computed as:

$$RT = \frac{RT_{2A} + RT_{2B}}{2}$$

$$RT = \frac{4RT_{2A}}{2}$$

$$RT_{2A} = \frac{RT}{2}$$

$$RT_{2B} = 3\frac{RT}{2}$$

Access and egress times for the two analysis zones can be computed as:

$$A_{2A} = \text{RIDE} \times 9.0 + \text{SCHD} \times 15 + \text{WAIT } (1.5 - 15)$$

$$E_{2A} = \text{RIDE} \times 9.0 + \text{WAIT } (1.5)$$

$$A_{2B} = \text{RIDE} \times 26.9 + \text{SCHD} \times 15 + \text{WAIT } (1.5 - \overline{15})$$

$$E_{2B} = \text{RIDE} \times 26.9 + \text{SCHD} \times 15 + \text{WAIT} \times 1.5$$

where RIDE, SCHD, and WAIT are discussed in Section 4.3 and, again, WAIT is assumed the same for feeder and line haul service.

B.2.6. Example 6 - Many-to-One Subscription (Adjustments Required)

The only difference between this example and the previous one is that the transfer point is located at the center of the northern side of the service area, rather than at its corner (see Figure B.34). The characteristics of the subscription DRT service are

- Area = 8 sq miles
- Vehicle fleet size = 4
- 15 miles per hour average speed
- Transfer point located at corner
- Fixed route headway of 30 minutes
- DRT vehicle operates on 60 minute cycles with half meeting each fixed route bus
- A 3 minute layover at the transfer point
- 40 demands per hour expected.

The central location of the transfer point results in slightly better DRT service than in the previous case. Also, the system can carry more people before becoming overloaded. It should be noted, however, that although better service is provided on the DRT service when the transfer point is more centrally located, at least part of the time savings may be offset by the longer linehaul time on the fixed route.

Figure B.34

New Location of Transfer Point for Example 6

Calculation of Service Times

The steps involved in the calculation of service times are described below.

Step 1: Account For Location of Transfer Point

To account for the different location of the transfer point in this example, a methodology similar to that employed in Example 4 is used. In this case, vehicles tour lengths are reduced by 0.5 miles, or approximately 2 minutes, in each direction. (The mean distance from a random point in the area to the transfer point in this case is 2.5 miles, vs. 3 miles in the previous case). The demand level is then adjusted according to the following formula (demand)

- Adj demand = demand + (reduction in mean time to get to transfer point/ cycle time) x demand[1]

$$= \frac{58}{60} \times 40 - \frac{2}{60}(40) = 38.7$$

Step 2: Calculate Ride Time

Look up ride time for adjusted demand on nomograph (Figure B.25-3)

- Ride time = 17.6

Step 3: Adjust ride time for shorter line haul

Adjust ride time for difference in line haul portion of the trip.

- Ride time adjusted = ride time - reduced line haul travel

  Ride time adjusted = 17.6 - 2 = 15.6 minutes

Table B.8 presents all of the level of service characteristics of this system.

---

[1]Note that, in the case of subscription service, there is no wait time curve (and hence no knee), therefore the base demand rate is used in place of the demand rate at the knee of the curve.

Table B.8. Service Times, Example 6*

	Transfer Time	Ride Time	Schedule Delay
Inbound	1.5 min.	15.6 min. (16.0)	15 min.
Outbound	1.5 min.	15.6 min. (16.0)	15 min.

*Computer modelled results in parentheses.

Calculation of Access/Egress Time

The key consideration in this example is that the ratio of access link distance, zone 2B to access link distance, zone 2A, is changed. Using the same approach as in the previous example (based on measurement of access link distance), it can be computed that:

$RT_{2A} = 7.8$

$RT_{2B} = 22.4$

Therefore, access and egress times are:

$A_{2A} = \text{RIDE} \times 7.8 + \text{SCHD} \times 15 + \text{WAIT} \times 1.5$

$E_{2A} = \text{RIDE} \times 7.8 + \text{WAIT} \times 1.5$

$A_{2B} = \text{RIDE} \times 22.4 + \text{SCHD} \times 15 + \text{WAIT} \times 1.5$

$E_{2B} = \text{RIDE} \times 22.4 + \text{SCHD} \times 15 + \text{WAIT} \times 1.5$

Appendix C Program Listings, Input/Output Descriptions

C.1 MANY-TO-MANY MODEL

Model Inputs

Variable	Columns	Type[1]	Description
K	1	I	0 → DRT model 1 → Shared Ride Taxi
A	2-6	R	Service Area Size (sq. miles)
VEH	7-11	R	Number of Vehicles
SAF	12-16	R	Street network adjustment factor
SPEED[2]	17-21	R	Base vehicle speed (miles/minute)
PT	22-26	R	Time per pickup (minutes)
DT	27-31	R	Time per dropoff (minutes)
DM1	32-36	R	Lower bound of demand level (demands/hour)
DM2	37-41	R	Upper bound of demand level (demands/hour)
NUM	42-45	I	Number of demand levels to be analyzed
FAF	46-50	R	Fleet adjustment factor (K_n in DRT Demand Final Report)
ALPHA	51-55	R	Manual Dispatch Adjustment factor (α in DRT Demand Final Report)

---

[1] "I" indicates variable is an integer input and should contain no decimal point. "R" indicates variable is a non integer input and should contain a decimal point.

[2] The manual version of the many-to-many model expresses speed in miles per minute. The computer program accepts this input in miles per hour to be more compatible with normal measures of speed.

BETA	56-60	R	Wait time/Ride time trade-off adjustment factor (β in DRT Demand Final Report)
DD	61-65	R	Average straight line trip distance (miles) 0. $\rightarrow$ DD = .52 SQRT(A)
DD1	66-70	R	Average straight line distance to transfer point 0. $\rightarrow$ DT = .63 SQRT(A)
PADV	71-75	R	Fraction of total requests which are advanced requests.

Each service description includes one card with the information listed above. If more than one service is being analyzed, one card for each should be included as input.

Service Characteristics for a single demand level may be obtained by setting DM1 at 0, DM2 at desired demand level and NUM to 1.

Model Outputs

MANY-TO-MANY DRT SERVICE

SYSTEM PARAMETERS
****** **********

AREA	NO. OF VEHICLES	BASE VEHICLE SPEED	PERCENT ADVANCED REQUESTS	DISTANCE TO TRANSFER	MANY TO MANY DISTANCE
4.0	8.00	15.00	0.00	1.28	1.04

PICKUP TIME	DROPOFF TIME	STREET NETWORK ADJUST FACTOR	FLEET ADJUST FACTOR	COMPUTER DISPATCH ADJUST FACTOR	WAIT-RIDE TRADEOFF FACTOR
1.00	0.50	1.2710	0.8500	0.5000	0.2000

SERVICE CHARACTERISTICS
******* ***************

DEMANDS PER HOUR	WAIT TIME	RIDE TIME TO TRANSFER	MANY TO MANY RIDE TIME
5.00	3.608	6.398	5.287
10.00	4.212	6.620	5.304
15.00	4.693	6.825	5.461
20.00	5.217	7.023	5.610
25.00	5.788	7.215	5.755
30.00	6.414	7.405	5.896
35.00	7.101	7.592	6.033
40.00	7.856	7.777	6.168
45.00	8.686	7.960	6.299
50.00	9.601	8.142	6.427
55.00	10.609	8.321	6.551
60.00	11.721	8.497	6.671
65.00	12.948	8.670	6.785
70.00	14.304	8.840	6.894
75.00	15.804	9.005	6.996
80.00	17.463	9.164	7.089
85.00	19.300	9.317	7.174
90.00	21.337	9.461	7.247
95.00	23.597	9.595	7.307
100.00	26.108	9.717	7.352
105.00	28.899	9.825	7.379
110.00	32.006	9.916	7.386
115.00	35.470	9.987	7.368
120.00	39.337	10.034	7.322

Program Listing

```
C
C                                 DRT AND SHARED RIDE TAXI SUPPLY MODEL
C
      REAL LAMBDA,LAMBD1
C
C *** READ DATA CARD
C
   50 READ(1,100,END=999)K,A,VEH,SAF,SPEED,PT,DT,DM1,DM2,NUM,FAF,ALPHA,
     1 BETA,DD,DD1,PADV
  100 FORMAT(I1,8F5.2,I4,6F5.2)
      V=SPEED/60.
      INDEX=0
C
C *** CALCULATE CONSTANTS LAMBDA, VEFF
      IF(DD1.EQ.0) DD1=.638*SQRT(A)
      IF (DD.EQ.0.)DD=.52*SQRT(A)
      DO 207 N=1,NUM
      LAMBDA=DM1/VEH+(DM2-DM1)/NUM/VEH*N
      LAMBD1=LAMBDA/FAF
      DEMAND=LAMBDA*VEH
      VEFF=(60.-LAMBDA*(PT+DT))*V/60.
      VEFF1=(60.-LAMBD1*(PT+DT))*V/60.
      INDEX=INDEX+1
      IF(INDEX.GT.31)INDEX=1
      IF(K.EQ.1) GO TO 60
C
C *** CALCULATE WT
C
      CWT=.219*SQRT((A+4.)/(VEH*FAF+12.))*LAMBD1**.9
      WTP=(SAF/(2.*VEFF1))*SQRT(A/VEH/FAF)*EXP(CWT)
      WT=(1.+ALPHA+BETA)*WTP
C
C *** CALCULATE TT
C
      CTT=.0843*(A*LAMBDA/VEH)**.7
      TT=(SAF*DD/VEFF)*EXP(CTT)
      TT1=(SAF*DD1/VEFF)*EXP(CTT)
      TT1=TT1-BETA*WTP
      TT=TT-BETA*WTP
      DIF=MAX(SAF*DD/V-TT,0.)
      DIF1=MAX(SAF*DD/V-TT1,0.)
      TT=TT+DIF
      TT1=TT1+DIF1
      WT=WT-DIF
      GAMMA=4.3*PADV**.8764*(LAMBDA/(LAMBDA+2.))**6.219
```

Program Listing (cont.)

```
      TTT=WT+TT
      TTT1=WT+TT1
      WT=WT+0.65*GAMMA*TTT
      TT=TT+0.35*GAMMA*TTT
      TT1=TT1+0.35*GAMMA*TTT1
      IF (INDEX .NE.1)GO TO 202
      WRITE(6,198)
  198 FORMAT(1H1,28X,'MANY-TO-MANY DRT SERVICE')
      GO TO 200
C
C
   60 CONTINUE
C *** CALCULATE WTS
C
      CWT=.203*SQRT((A+4.)/(VEH*FAF+12.))*LAMBD1
      WTP=SAF/2./VEFF1*SQRT(A/VEH/FAF)*EXP(CWT)
      WT=(1.+ALPHA+BETA)*WTP
C
C
      CTT=.0843*(A*LAMBDA/VEH)**.7
      TT=(SAF*DD/VEFF)*EXP(CTT)
      TT1=(SAF*DD1/VEFF)*EXP(CTT)
      TT=TT-BETA*WTP
      TT1=TT1-BETA*WTP
      DIF=MAX(SAF*DD/V-TT,0.)
      DIF1=MAX(SAF*DD/V-TT1,0.)
      TT=TT+DIF
      TT1=TT1+DIF1
      WT=WT-DIF
      GAMMA=4.3*PADV**.8764*(LAMBDA/(LAMBDA+2.))**6.219
      TTT=WT+TT
      TTT1=WT+TT1
      WT=WT+0.65*GAMMA*TTT
      TT=TT+0.35*GAMMA*TTT
      TT1=TT1+0.35*GAMMA*TTT1
      IF(INDEX.NE.1) GO TO 202
      WRITE(6,199)
  199 FORMAT(1H1,28X,'SHARED RIDE TAXI SERVICE')
C
C
  200 WRITE(6,201)A,VEH,SPEED,PADV,DD1,DD
  201 FORMAT(//,32X,'SYSTEM PARAMETERS',/,32X,'****** **********',//,
     1 30X,'      BASE   PERCENT  DISTANCE   MANY TO',/,
     2 20X,'    NO. OF   VEHICLE  ADVANCED        TO       MANY',/,
     3 16X,'AREA  VEHICLES     SPEED  REQUESTS  TRANSFER  DISTANCE',/,
     3 10X,6(' ---------'),/10X,F10.1,F10.2,4F10.2,//
     5 30X,'    STREET',10X,' COMPUTER     WAIT-')
      WRITE(6,206) PT,DT,SAF,FAF,ALPHA,BETA
```

Program Listing (cont.)

```
  206 FORMAT(
     6 30X,'   NETWORK     FLEET  DISPATCH      RIDE',/
     7 14X,'PICKUP   DROPOFF    ADJUST    ADJUST    ADJUST  TRADEOFF',/
     8 16X,'TIME      TIME     FACTOR    FACTOR    FACTOR    FACTOR',/
     9 10X,6(' ---------'),/10X,2F10.2,4F10.4)
      WRITE(6,204)
  204 FORMAT(//29X,'SERVICE CHARACTERISTICS',/29X,
     1 '******* ***************')
      WRITE(6,205)
  205 FORMAT(/18X,'DEMANDS',15X,'      RIDE TIME   MANY TO MANY',/
     1 17X,'PER HOUR      WAIT TIME    TO TRANSFER      RIDE TIME'/
     2 10X,4(' --------------'))
C
C *** PRINT RESULTS
C
  202 WRITE(6,203)DEMAND,WT,TT1,TT
  203 FORMAT( 8X,F15.2,3F15.3)
207   CONTINUE
      GO TO 50
C
999   CONTINUE
      CALL EXIT
      END
```

C.2 MANY-TO-ONE CYCLED SERVICE

Model Inputs

Variable	Columns	Type[1]	Description
DEM1	1-4	R	Lower bound of demand range (demands/hour)
DEM2	5-8	R	Upper bound of demand range
PMTM	9-12	R	Portion of demands which are many-to-many
PI	13-16	R	Portion of demands which are inbound many-to-one
SI	17-20	R	Portion of many-to-many demands served entirely on outbound portion of vehicle tour
SO	21-24	R	Portion of many-to-many demands served entirely on outbound portion of vehicle tour
NUM	25-28	I	Number of demand levels between lower and upper limits to be analyzed
LO	29-32	R	Layover time at transfer point (minutes)
LH	33-36	R	Linehaul distance outside service area to transfer point
SPEED[2]	37-40	R	Base vehicle speed (miles per hour)
SAF	41-44	R	Street network adjustment factor ($1.2 < SAF < 1.4$)
C	45-48	R	Cycle time of DRT vehicles (minutes)
A	49-52	R	Size of service area (sq. miles)
PT	53-56	R	Pickup time (minutes)
DT	57-60	R	Dropoff time minutes)
VEH	61-64	R	Number of vehicles

---

1 "I" indicates an integer input (no decimal point),"R" indicates a non-integer input (includes decimal point).

2 Note the units of speed differ from those used in the manual version of the many-to-one cycled service model.

HDWY	65-68	R	Headway of DRT vehicles at the transfer point (minutes)
TLOC	69-72	R	1 → transfer in center of service area other → transfer on service area boundary or external

Each service description includes one card with the information listed above. If more than one service is being analyzed, one card for each should be included as input.

Service characteristics for a single demand level may be obtained by setting DEM1 = 0, DEM2 to the desired demand level and NUM to 1.

Model Output

MANY TO ONE CYCLED SERVICE

SYSTEM PARAMETERS
****** **********

AREA	NO. OF VEHICLES	DRT VEHICLE CYCLE TIME	DRT HEADWAY AT TRANSFER	TRANSFER LOCATION	LINEHAUL TIME	LAYOVER TIME	BASE VEHICLE SPEED	PICKUP TIME	DROPOFF TIME	STREET NETWORK ADJUST FACTOR	PERCENT MANY TO MANY	PERCENT INBOUND FEEDER	PERCENT OUTBOUND FEEDER
6.0	4.0	30.0	10.0	EDGE	0.000	1.000	15.000	1.000	0.500	1.270	0.000	0.500	0.500

SERVICE CHARACTERISTICS
******* ***************

DEMANDS PER HOUR	WAIT TIME AT TRANSFER	WAIT TIME AT HOME	RIDE TIME OUTBOUND	RIDE TIME INBOUND	RIDE TIME MANY-MANY	VEHICLE DOWN TIME	PICKUP POOL SIZE	RENDEVOUS TOUR TIME	DSTRIBUT TOUR TIME	COLLECT TOUR TIME	MINIMUM DEADHEAD TIME
5.00	0.50	6.14	8.47	9.24	10.35	13.37	0.31	12.20	0.23	2.28	1.92
10.00	0.50	7.27	8.64	9.99	10.81	7.74	0.62	13.86	0.87	4.54	2.99
15.00	0.50	8.82	8.99	10.28	11.14	5.29	1.11	15.07	1.82	4.01	3.80
20.00	0.50	11.85	9.49	10.66	11.58	2.89	1.85	15.96	2.95	4.08	4.13
25.00	0.50	15.79	10.09	10.97	12.04	1.04	2.91	16.61	4.17	4.29	3.89
30.00	0.50	29.32	10.74	10.83	12.30	0.61	6.08	17.08	5.44	3.78	3.08
35.00	0.50	73.38	11.42	10.54	12.60	0.58	16.80	17.43	6.72	3.21	2.07
40.00	0.50	315.29	12.10	10.23	12.89	0.55	79.75	17.69	7.98	2.58	1.21
45.00	0.50	93261.72	12.77	9.88	13.15	0.53	26231.00	17.87	9.21	1.88	0.51

Program Listing

```
C
C ***                  MANY TO ONE CYCLED SERVICE MODEL
C
C
      IMPLICIT REAL(A-L)
      DATA TLOC1/'    '/,TLOC2/'EDGE'/,TLOC3/'  CE'/,TLOC4/'NTER'/
    5 READ(1,200,END=44)DEM1,DEM2,PMTM,PI,SI,SO,NUM,LO,LH,SPEED,SAF,C,
     1 A,PT,DT,VEH,DRHDWY,TLOC
  200 FORMAT(6F4.2,I4,8F4.2,3F4.2)
      V=SPEED/60.
C
C *** DETERMINE MANY TO MANY DEMAND RATE ADJUSTMENTS
C
      PSI=SI*C/VEH/DRHDWY
      PSO=SO*C/VEH/DRHDWY
      PO=1.-PMTM-PI
      PIMTM=PMTM*(1.+PSI-PSO)
      POMTM=PMTM*(1.+PSO-PSI)
      APV=A/VEH*C/DRHDWY
      IF(TLOC .LE. 0.5) LFAC=0.638
      IF(TLOC .GT. 0.5) LFAC=0.376
      TLOCA=TLOC1
      TLOCB=TLOC2
       IF(TLOC .GT. 0.5) TLOCA=TLOC3
       IF(TLOC .GT. 0.5) TLOCB=TLOC4
      NDEX=0
      ALP=1.01*SAF*SQRT(A/VEH*C/DRHDWY)/V
      DO 1 N=1,NUM
      NDEX=NDEX+1
      IF(NDEX .EQ.40) NDEX=1
      IF(NDEX.NE.1) GO TO 135
      WRITE (6,102)
  102 FORMAT('1',48X,'MANY TO ONE CYCLED SERVICE',///52X,
     1 'SYSTEM PARAMETERS'/52X,'****** **********'/25X,'DRT      DRT',
     2 54X,'   STREET'/21X,'VEHICLE  HEADWAY',27X,'     BASE',
     2 18X,' NETWORK  PERCENT  PERCENT  PERCENT',/10X,
     3 '   NO. OF    CYCLE       AT TRANSFER LINEHAUL  LAYOVER',
     4 '  VEHICLE   PICKUP  DROPOFF   ADJUST  MANY TO  INBOUND',
     5 ' OUTBOUND')
      WRITE(6,113)
  113 FORMAT(1X,'     AREA VEHICLES     TIME TRANSFER',
     2 ' LOCATION     TIME     TIME     SPEED     TIME     TIME',
     3 '   FACTOR     MANY   FEEDER   FEEDER',/,1X,14(' --------'))
      WRITE(6,110)A,VEH,C,DRHDWY,TLOCA,TLOCB,LH,LO,SPEED,PT,DT,SAF,
     1 PMTM,PI,PO
  110 FORMAT(1X,4F9.1,1X,2A4,9F9.3)
```

Program Listing (cont.)

```
      WRITE(6,111)
  111 FORMAT(///49X,'SERVICE CHARACTERISTICS'/49X,
     A '******* ***************',//1X,'   DEMANDS',
     1 '        WAIT       WAIT       RIDE       RIDE       RIDE   VEHICLE',
     2 '     PICKUP RENDEVOUS  DSTRIBUT   COLLECT   MINIMUM',/1X,
     3 '        PER    TIME AT       TIME       TIME       TIME      TIME',
     4 '        DOWN       POOL       TOUR       TOUR       TOUR  DEADHEAD')
      WRITE(6,114)
  114 FORMAT (1X,'        HOUR   TRANSFER   AT HOME  OUTBOUND   INBOUND',
     1 ' MANY-MANY        TIME       SIZE       TIME       TIME      TIME',
     2 '       TIME'/1X,12(' ---------'))
  135 DEM=DEM1+(DEM2-DEM1)/NUM*N
      LAMA=(PO+POMTM)*DEM/60.
      LAMB=(PI+PIMTM)*DEM/60.
      LMCA=LAMA*C/VEH
      LMCB=LAMB*C/VEH
      PRO=1.-EXP(-LMCA)
      L1=LFAC*SAF*SQRT(A)/V+LH+PT
      L2=LU
      L3=(LFAC*SAF*SQRT(A)/V+LH+DT)*PRO
      L=L1+L2+L3
C
C *** CALCULATE DISTRIBUTION TOUR TIME
C
      DELTA=1.-(LMCA/PRO-1.)/8./(LMCA/PRO-0.5)**2
      R=(LMCA/PRO-1.)*DT*PRO
      R=R+1.01*SAF*SQRT(APV)/V*(DELTA*SQRT(LMCA/PRO-0.5)
     1 -SQRT(0.5))*PRO
C
C *** CALCULATE STEADY STATE PICKUP POOL
C
      K=(C-L-R-LMCB*PT)/ALP
      XS=(MAX(0.,(0.5+LMCB-K**2)/2/K))**2+LMCB
      Y=LMCB+MAX(0.,K-SQRT(LMCB+0.5)+SQRT(0.5))
      STXS=(XS-Y)/SQRT(Y)
      CALL NORMAL(STXS,PHE,PHI)
      YP=XS-(XS-Y)*PHE-SQRT(Y)*PHI
      XSP=XS+AMAX1(0.,LMCB-YP)
C
C *** CALCULATE COLLECTION TOUR TIME
C
      PG0=1.-EXP(-XSP)
      DELTB=1.0-(XSP/PG0-0.5)/8./(XSP/PG0)**2
      G=(LMCB/PG0-1)*PG0*PT
      G=G+1.01*SAF*SQRT(APV)/V*(DELTB*SQRT(XSP/PG0-0.5)
     1 -SQRT((XSP-LMCB)/PG0))*PG0
```

Program Listing (cont.)

```
C
C *** CALCULATE DEADHEAD AND VEHICLE DOWN TIME
C
      D=C-L-R-G
      IF(D .LT. 0.) GO TO 5
      DMIN =PGO*(1.-PRO)*LFAC*SAF*SQRT(A)/V
     1 +PGO*PRO*.505*SAF*SQRT(APV/(XSP/PGO))/V
C
C *** CALCULATE LEVEL OF SERVICE
C
      WTI=XSP*DRHDWY/LMCB-DRHDWY/2.+G/2.
      WTO=L2/2
      RTI=L1+G/2*PGO
      RTO=R/2.*PRO+L3/PRO
      RTM=(1.-PSO-PSI)*(RTO+RTI+L2)+PSI*MAX(G,.505*SQRT(APV)/V*SAF)/3.+
     1 PSO*MAX(R,.505*SAF*SQRT(APV)/V)/3.
      DOWN=D-DMIN
    1 WRITE(6,100)DEM,WTO,WTI,RTO,RTI,RTM,DOWN,XSP,L,R,G,DMIN
  100 FORMAT(1X,12F10.2)
      GO TO 5
   44 CONTINUE
      CALL EXIT
      END
      SUBROUTINE NORMAL(X,DEN,CUM)
C     SUBROUTINE NORMAL CALCULATES STANDARDIZED NORMAL CUMULATIVE AND
C     PROBABILITY DENSITY FUNCTION.  THE INPUT  X IS THE STANDARDIZED
C     VALUE OF THE RANDOM VARIABLE AND THE OUTPURS ARE DEN THE VALUE OF
C     THE PDF AND CUM, THE VALUE OF THE CDF.
      DIMENSION PHE(0:400),PHI(0:400)
      LOGICAL FIRST,TRUE
      DATA FIRST /.TRUE./,FALSE /.FALSE./,PI /3.14159/
      IF (.NOT. FIRST) GO TO 2
      FIRST = .FALSE.
      PHI(0)=.5
      PHE(0)=1./SQRT(2.*PI)
      DO 1 I=1,400
      PHE(I)=1./SQRT(2.*PI)*EXP(-.5*(FLOAT(I)/100.)**2)
    1 PHI(I)=PHI(I-1)+PHE(I)/100.
    2 XP=ABS(X)*100.
      IXP=IFIX(XP)
      IF (IXP .GT. 399) GO TO 3
      DEN=PHE(IXP)+(XP-FLOAT(IXP))*(PHE(IXP+1)-PHE(IXP))
      CUM=PHI(IXP) +(XP-FLOAT(IXP))*(PHI(IXP+1)-PHI(IXP))
      IF (X .LT. 0.) CUM=1-CUM
      RETURN
    3 CUM=1.
      DEN=.0001
      IF (X .LT.0.) CUM=1-CUM
      RETURN
      END
```

C.3 SUBSCRIPTION SERVICE MODEL

Model Inputs

Variable	Columns	Type [1]	Description
DEM1	1-5	R	Lower bound for range of demands to be analyzed (demands/ hour)
PROD2	6-10	R	Upper bound for range of demands to be analyzed (demands/hour)
NUM	11-15	I	Number of demand levels between upper and lower bound to be analyzed
NVEH	16-20	R	Number of vehicles available to work in service area
DRHDWY	21-25	R	Headway of DRT vehicles at the transfer point
CYCLE	26-30	R	Cycle time for subscription service vehicles. This is the time available to perform tour. This value must be an integer multiple of HDWY.
X	31-35	R	Length of service area along the X axis (in miles)
Y	36-40	R	Length of service area along the Y axis (in miles)
SPEED[2]	41-45	R	Base vehicle speed (before stops) in miles per hour
PT	46-50	R	Pickup/dropoff time in minutes - pickup times for feeder, dropoff time for distributor service
LO	51-55	R	Layover time at transfer point in minutes
VCAP	56-60	R	Seating capacity of DRT vehicles

[1] "I" indicates integer input (no decimal),"R" indicates non-integer input (includes decimal).

[2] Note unit of speed differs from that presented in the manual version of the subscription model.

XLOC1	61-65	R	X coordinate of transfer point. If transfer point is outside service area, coordinate should be negative (never greater than X)
YLOC1	66-70	R	Y coordinate of transfer point. YLOC1 should never be greater than Y.

A complete analysis will be performed for the specified productivities and vehicles. More than one scenario may be analyzed in a single run by including more than one input card.

Service Characteristics for a single demand level can be obtained by setting PROD1 at 0, PROD2 at the desired productivity level and NUM=1.

Model Outputs

MANY TO ONE SUBSCRIPTION SERVICE

SYSTEM PARAMETERS

****** **********

AREA	NO. OF VEHICLES	DRT VEHICLE CYCLE TIME	DRT HEADWAY AT TRANSFER	TRANSFER POINT COORDINATES	LAYOVER TIME	BASE VEHICLE SPEED	PICKPUP/ DROPOFF TIME
6.00	4.00	30.00	10.00	(1.2, 0.0)	1.000	15.000	0.750

SERVICE CHARACTERISTICS

****

DEMANDS PER HOUR	WAIT TIME AT TRANSFER	SCHEDULE DELAY	AVERAGE RIDE TIME	VEHICLE DOWN TIME	ROUNDTRIP TOUR TIME	DEADHEAD TOUR TIME	COLLECT DISTRIBUT TIME
5.00	0.50	5.00	9.70	11.89	18.11	7.41	9.06
10.00	0.50	5.00	9.98	9.81	20.19	8.17	10.39
15.00	0.50	5.00	10.38	6.18	23.82	9.47	12.71
20.00	0.50	5.00	10.76	3.58	26.42	10.32	14.46
25.00	0.50	5.00	11.19	1.47	28.53	10.90	15.99
30.00	*DEMAND CANNOT BE SERVED*						

Program Listing

```
C
C ***                          SUBSCRIPTION SERVICE MODEL
C
      IMPLICIT REAL(A-L)
      DIMENSION WID(2),LEN(2)
C
C *** READ INPUT DATA
C
    1 READ(1,100,END=999)DEM1,DEM2,NUM,NVEH,DRHDWY,CYCLE,X,Y,SPEED,PT,
     2 LO,VCAP,XLOC1,YLOC1
  100 FORMAT(2F5.2,I5,I5,10F5.2)
      V=SPEED/60.
      XLOC=XLOC1
      YLOC=YLOC1
      A=X*Y
      IF (XLOC.GT.X.OR.YLOC.GT.Y)GO TO 810
      IF(CYCLE.LT.HDWY)GO TO 830
C
C *** CALCULATION OF EXTERNAL LINEHAUS DISTANCE
C
      LEXT=0.
      IF(XLOC.LT.0.0 .AND. YLOC.LT. 0.0)GO TO 390
      IF(XLOC.LT.0.0)GO TO 380
      IF(YLOC.LT.0.) GO TO 370
      GO TO 400
  370 LEXT=-YLOC
      YLOC=0.
      GO TO 400
  380 LEXT=-XLOC
      XLOC=0.
      GO TO 400
  390 LEXT=-(XLOC+YLOC)
      XLOC=0.
      YLOC=0.
  400 CONTINUE
C
C *** BEGIN LOOP THROUGH DEMAND LEVELS
C
      VEH=FLOAT(NVEH)
      NDEX=0
      DO 499 N2=1,NUM
      DEM=DEM1+(DEM2-DEM1)/FLOAT(NUM)*FLOAT(N2)
      PROD=DEM/VEH
```

Program Listing (cont.)

```
C
C *** WRITE HEADINGS
C
      NDEX=NDEX+1
      IF(NDEX.GE.40) NDEX=1
      IF(NDEX.NE.1)GO TO 409
      WRITE(6,401)
  401 FORMAT(1H1,25X,'MANY TO ONE SUBSCRIPTION SERVICE')
      WRITE(6,402)
  402 FORMAT(/33X,'SYSTEM PARAMETERS'/33X,'****** **********'/
     1 19X,'      DRT        DRT'/19X,' VEHICLE  HEADWAY',32X,'BASE',
     2 '  PICKPUP/''/13X,'NO. OF    CYCLE        AT    TRANSFER POINT',
     3 '  LAYOVER  VEHICLE  DROPOFF'/6X,'AREA VEHICLES     TIME',
     4 ' TRANSFER       COORDINATES     TIME    SPEED     TIME'/
     5 1X,4(' --------'),' ----------------',3(' --------'))
      WRITE(6,404) A,VEH,CYCLE,DRHDWY,XLOC1,YLOC1,LO,SPEED,PT
  404 FORMAT(1X,4F9.2,5X,'(',F5.1,',',F5.1,')',3F9.3/)
      WRITE(6,403)
  403 FORMAT(30X,'SERVICE CHARACTERISTICS'/30X,'***********************'
     1 /17X,'WAIT',50X,'  COLLECT'/
     2 4X,'DEMANDS   TIME AT  SCHEDULE   AVERAGE   VEHICLE',
     3 ' ROUNDTRIP  DEADHEAD DISTRIBUT'/3X,'PER HOUR  TRANSFER',
     4 '      DELAY RIDE TIME DOWN TIME TOUR TIME TOUR TIME      TIME'/
     5 1X,8(' ---------'))
  409 CONTINUE
      IF(PROD.GT.VCAP*60./CYCLE) GO TO 498
C
C *** SET UP SUBZONES
C
      IF(X.GT.Y)GO TO 410
      WID(1)=X
      LEN(1)=YLOC
      WID(2)=X
      LEN(2)=Y-YLOC
      TLOC=MIN(XLOC,X-XLOC)
      GO TO 420
  410 WID(1)=Y
      LEN(1)=XLOC
      WID(2)=Y
      LEN(2)=X-XLOC
      TLOC=MIN(YLOC,Y-YLOC)
  420 CONTINUE
  430 TRT=0.
      DO 450 N=1,2
```

Program Listing (cont.)

```
C
C *** CALCULATE SUBZONE ATTRIBUTES
C
      AREA=WID(N)*LEN(N)
      IF(AREA.LE.0.0001)GO TO 450
      SVEH=VEH*AREA/X/Y
      SECT=SVEH/CYCLE*DRHDWY
      STOPS=PROD*CYCLE/60.
      IF(STOPS.LT.1.)STOPS=1.
C
C *** IF SUBZONE CONTAINS LESS THAN ONE SECTOR,
C ***     MERGE IT WITH ANOTHER SECTOR
C
      IF(SECT.LT.1.)GO TO 600
      ASPECT=LEN(N)/WID(N)*SECT
      IF(ASPECT.LT.1.)ASPECT=1./ASPECT
C
C *** CALCULATION OF LINEHAUL DISTANCES
C
      NLOC=TLOC/(WID(N)/SECT)+1
      FD=TLOC-FLOAT(NLOC-1)*WID(N)/SECT
      DL=((FD+(FLOAT(NLOC)-2.)*WID(N)/2./SECT)*(FLOAT(NLOC)-1.)+
     2    (WID(N)/SECT-FD+(MAX(0.,SECT-FLOAT(NLOC)-1.))*WID(N)/2./SECT)
     3    *(SECT-FLOAT(NLOC)))/SECT
C
      DSL=(WID(N)/SECT+LEN(N))*(STOPS/(STOPS+1.))*(SECT-1.)
      DSL=DSL+(MAX(FD,WID(N)/SECT-FD+LEN(N)))*STOPS/(STOPS+1.)
      DSL=DSL/SECT
C
C *** CALCULATE COLLECTION/DISTRIBUTEION TOUR LENGTH
C
      DCD=(WID(N)/SECT+LEN(N))*((0.8-0.18/ASPECT)+(0.01+0.084*
     2    *SQRT(ASPECT))*STOPS-(0.31-0.18/ASPECT+0.084/SQRT(ASPECT))
     3    /STOPS)
C
C *** CALCULATE ROUND TRIP TIME
C
      T=2.*(DL+LEXT)/V+(DSL+DCD)/V+STOPS*PT+LO
C
C     CHECK FOR SUFFICIENT CYCLE TIME FOR SERVICE
C
      IF (T.LE.CYCLE)GO TO 449
C
C *** IF CYCLE TIME IS TOO LONG DEMAND CANNOT BE SERVED
C
  498 WRITE(6,109)DEM
  109 FORMAT(1X,F10.2,'    *DEMAND CANNOT BE SERVED*')
      GO TO 1
```

Program Listing (cont.)

```
C
C *** CALCULATE LEVEL OF SERVICE FOR SUBZONE
C
  449 ART=(DL+LEXT)/V+(DCD/V+PT*STOPS)*(STOPS+1.)/(2.*STOPS)
      TRT=TRT+ART*SVEH
  450 CONTINUE
      AVRT=TRT/VEH
      AVSD=DRHDWY/2.
      AVWT=LO/2.
C
C ** OUTPUT SERVICE CHARACTERISTICS
C
      DOWN=CYCLE-T
      DHT=(LEXT+DL+DSL)/V
      DCT=STOPS*PT+DCD/V
      WRITE(6,405) DEM,AVWT,AVSD,AVRT,DOWN,T,DHT,DCT
  405 FORMAT(8F10.2)
  499 CONTINUE
      GO TO 1
C
C *** MERGE SMALL ZONE IN WITH OTHER ZONE
C
  600 CONTINUE
      IF(VEH/CYCLE*HDWY.LE.2.)GO TO 610
      LEN1=MAX(X,Y)/VEH*CYCLE/HDWY
      DIF=LEN1-LEN(N)
      IF(DIF.GT.LEN(N))GO TO 610
      LEN(1)=LEN1
      LEN(2)=MAX(X,Y)-LEN1
      GO TO 430
  610 LEN(1)=MAX(X,Y)
      LEN(2)=0.
      GO TO 430
C
C *** TRAP FOR ILLEGAL TRANSFER LOCATION
C
  810 WRITE(6,103)XLOC,YLOC
  103 FORMAT(' TRANSFER LOCATION ILLEGAL --',2F5.2)
      GO TO 1
C
C *** TRAP FOR ILLEGAL CYCLE HEADWAY COMBINATION
C
  830 WRITE(6,106)HDWY,CYCLE
  106 FORMAT(' ILLEGAL HEADWAY-CYCLE COMBINATION -- HEADWAY=',F5.2,
     2    ' CYCLE=',F5.2)
      GO TO 1
  999 CONTINUE
      CALL EXIT
      END
```

APPENDIX D

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed that no new innovation, discovery, or invention of a patentable nature was made. However, this report contains a number of advances to the state-of-the-art of demand-responsive supply (service models). A number of improvements have been made to a set existing supply models. For example, the many-to-many dynamic dispatch model has been expanded to handle the impacts of advanced request customers. The many-to-one cycled service model now includes capabilities for analyzing systems with multiple vehicles, passengers not travelling to or from the transfer point, and a more accurate representation of low productivity level of service. The subscription service model provides for a more accurate representation of tours by redefinition of sector shape and configuration. A computer program has been written to allow the models to be used fairly easily as a sketch planning tool.

GLOSSARY

Access time - Time spent getting from origin to line haul vehicle.

Advance requests - Requests for DRT service that are made substantially in advance of the time of the desired trip.

Checkpoint Service - A DRT system where vehicle travel on demand but only to a set of pre-determined checkpoints; checkpoint many-to-many, checkpoint many-to-one, and checkpoint subscription services are all feasible.

Collection tour - Tour made by DRT vehicle in many-to-one service to pick-up passengers.

Computer dispatching - Computer assignment of DRT service request to vehicles.

Cycled service - A DRT service in which vehicles are scheduled to leave and return to a given point at pre-specified times.

Deadhead time - Time spent idle by DRT vehicle, except time spent transfer point.

Demand rate - Demands per hour for DRT service.

Demand-responsive transportation (DRT) - A family of transportation service in which vehicles in some manner respond to the demands of the passengers.

Discrete run time service - See cycled service.

Distributor tour - Tour made by DRT vehicle in many-to-one service dropping off passengers.

Dynamic dispatch - A DRT system in which vehicles are dispatched in response to passenger requests on a dynamic basis, with the vehicle tour not scheduled in advance.

Egress Time - Time spent getting from line haul vehicle to destination.

Feeder service - A transportation service designed primarily to transport passengers to a point where they can catch some other line haul service.

Immediate request - Request for DRT service made at the desired travel time.

Impedance - Weighted components of travel time.

Inbound - Feeder vehicle headed towards transfer point.

In-phase operation - Operation of a many-to-one cycled service such that all vehicles in the service area meet at the transfer point at the same time.

In-vehicle time (IVTT) - Component of travel time spent on board a vehicle.

Headway - Time between schedule arrival of line haul or DRT vehicle.

Layover time - Time DRT vehicle scheduled to be idle at transfer point, to allow time for transfers and reduce unreliability.

Line haul - Fixed route service, "External line haul," "service area line haul," and "sector line" terms used to denote fixed components of vehicle tour in subscription service.

Load time - Time required for passenger to board transit vehicle.

Many-to-many service - A form of DRT service in which service is provided from any point in the service area to any other point.

Many-to-one service - A DRT system in which passengers can travel from any point in a service area to a single given point, or vice versa.

Outbound - Feeder vehicle headed away from transfer point.

Out-of-phase operation - Operation of a many-to-one cycled service such that alternate DRT vehicles meet alternate line haul vehicles.

Out-of-vehicle time (OVTT) - Component of travel time not spent on a vehicle.

Rendezvous time - The time between the last pick-up on one cycle and the first drop-off on the next cycle (for a cycled service).

Ride time - Time spent on board a (transit) vehicle.

Route deviation - A DRT system where vehicles follow a route but are free to deviate from the route to pick up or drop off passengers.

Schedule delay - Delay caused to transit passenger by schedules not coinciding to the time they would actually like to travel.

Service area - The area in which a DRT system provides service.

Street network adjustment factor - Ratio of street distance to airline distance.

Subarea - Section of DRT service area assigned to a particular vehicle or set of vehicles.

Sub-modal split - The split among all possible access/egress modes of transit demand to and from a given point.

Subscription service - A DRT system in which passengers reserve service on a regular basis.

Transfer point - Point at which transfers are made between feeder and line haul vehicles.

Transfer time - Time spent after leaving one (transit) vehicle before boarding another.

ULOAD - UTPS program for assigning demand to different links in the network.

UMATRIX - UTPS program for building impedance matrices.

UMODEL - UTPS program for demand modeling (mode split estimation).

UNET - UTPS program used for network building.

Unload time - Time required for passengers to board transit vehicle.

UPATH - UTPS program used for developing shortest paths.

UPSUM - UTPS program which extracts impedance values from paths.

UTPS - Urban Transportation Planning System - A set of computer programs designed for the analysis of urban transportation systems.

Vehicle tour - Sequence of stops of a DRT vehicle.

Wait time - Time spent waiting for a (transit) vehicle. For immediate request DRT systems, it is the time between the call for service and the arrival of the vehicle. For a fixed route service, it is the time spent by a passenger between arrival at the transit stop and arrival of the vehicle.

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